APPLIED RANGE ECOLOGY OF REINDEER (*Rangifer tarandus tarandus*) ON THE SEWARD PENINSULA, ALASKA

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A

THESIS

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ABSTRACT

Linking variation of the environment to animal production is key to successful range management. Ecological site descriptions (ESDs) are landscape units used by land managers for the grazing management of domestic reindeer (*Rangifer tarandus tarandus*) on the Seward Peninsula, Alaska. This study investigated the appropriateness of using ESDs for the grazing management of reindeer and explored the use of alternate units to link landscape variation to animal production.

ESD composition of reindeer ranges varied across the Seward Peninsula, but there was no relationship to either animal production, estimated by June calf weight and cow/calf ratios, or reindeer serum and tissue mineral concentrations. I have shown that reindeer do not graze uniformly across ESDs, but are selective, both temporally and spatially, in what they consume. Reindeer diet selection and animal production appear to be driven by temporal variation in the nutritional characteristics of individual forage species. Biomass production and seasonal nutritional characteristics of forage species were used develop a computerized mapping program for reindeer producers to identify high quality grazing areas.

Production among herds was related with identified forage sources of protein in the diet. Reindeer in herds with smaller June calves consumed more catkins, stems and leaf buds of shrubs in May, presumably to compensate for lower protein reserves. Diets of reindeer and June calf weight were significantly predicted by the $\delta^{15}N$ ‰ differential between antler core (AC) and antler periosteum (AP). Although animal production was

related to landscape stratification at the species level, data showed that weather patterns affected forage nutrient concentration and foraging accessibility at a landscape level. Body weight and growth of female calves and the proportion of yearlings lactating the next summer were positively correlated with spring temperature and negatively correlated with winter severity and summer temperature.

Land managers are using ESDs to monitor and assess the impact of grazing, but I have shown that landscape variation described at a multitude of scales other than ESD are linked to grazing patterns and animal production. I concluded that these alternative landscape units be integrated into reindeer range management currently being practiced on the Seward Peninsula.

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List of Abbreviations and Acronyms

ADF	Acid Detergent Fiber
ATV	All Terrain Vehicle
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
$\delta^{15}N$	Delta 14/15 nitrogen isotope concentration
E	Exponential notation
Ecosite	Ecological site
ESD	Ecological site description
g	gram
GDD	Growing degree days
GMT	Generic mapping tools
ha	hectare
IVTDMD	in-vitro-true-dry-matter-digestibility
JD	Julian date
kg	kilogram
km	kilometer
m	meter
NDF	neutral detergent fiber
N	nitrogen
PH	phenology
RHA	Reindeer Herders Association

µg	microgram
SNDD	Snow depth days
USDA	United States Department of Agriculture
-NRCS	Natural Resources Conservation Service, previously known as the Soil Conservation Service
UAF	University of Alaska, Fairbanks
-RRP	Reindeer Research Program
USGS	United States Geological Survey
WACH	Western Arctic Caribou Herd
WSEV	Winter Severity Index
WVD	Wind Velocity Days

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CHAPTER 1

Introduction

Rangifer in Alaska

Pastoralism has been practiced for thousands of years throughout the world, but recently the management of livestock on rangelands has changed because of shifting land use patterns and loss of access to large, public grazing areas. Current range management based on the concepts of ecological site descriptions, sustained yield, controlled stocking densities, and rotational grazing has now replaced extensive herding practices in many areas of the United States. The ecology and consequences of current range management, as it applies to traditional livestock and temperate grasslands of North America is relatively well known but intensive range management is now being practiced on unique rangelands using unconventional livestock species.

Tundra grazing systems, while not particularly productive, are capable of sustaining relatively few species, but large populations of mammalian grazers such as caribou/reindeer (*Rangifer*). *Rangifer* has been a major source of meat and milk for humans throughout a tremendous geographic area and across a time span of tens of thousands of years (Burch, 1972). Known human dependence on *Rangifer* has a long history dating back to the Middle Pleistocene (Banfield, 1961). In recent times, these animals have been important in North America for many Eskimo, Northern Athapaskan, and Northern Algonkian people and in Eurasia for Saami, Samoyed, Northern Tungus and Siberian peoples (Burch, 1972). Whereas harvesting of wild populations of caribou

(Rangifer tarandus grantii) has historically been and currently is a major, but tenuous, food source, the predictability and productivity of harvest has increased through domestication and herding of reindeer (*Rangifer tarandus tarandus*). In Russia, animal production was increased up to 20 fold when herding of domestic reindeer replaced hunting of wild reindeer (Andreev, 1975).

The Seward Peninsula grazing system

Both humans and grazing animals traveled across the Bering Land Bridge from Asia and settled in North America. A group of these people, the Inupiaq, settled in Northwestern Alaska, including the Seward Peninsula, and have for thousands of years relied upon populations of marine and terrestrial animals for their survival, including seals, whales, fish, caribou and musk oxen (Ray, 1983; Kurtén and Anderson, 1980). The hunting-gathering economies of the Inupiaq required them to interact with the landscape in a fashion where harvesting strategies tracked ephemerally abundant grazing animals such as caribou (Ray, 1983; Burch, 1998).

There is archeological evidence demonstrating that caribou were present on the Seward Peninsula and were harvested as a significant food source by the Inupiaq for hundreds of years before the influx of Europeans (Koutsky, 1981). While all Inupiaq harvested caribou if they were encountered, some settlements like Buckland, Kauwerak, Koyuk, Goodhope, Iglutalik, and Egavik developed cooperative caribou hunting strategies. Caribou were driven through makeshift alleyways into enclosures or lakes where they were captured with snares, harvested with spears or slaughtered by men in

kayaks (Spiess, 1979). Residents of these settlements specialized in this subsistence pattern and recognized themselves mainly as caribou hunters as depicted in artwork that showed both bow and arrow and spears as the main tools for harvest.

It wasn't until Captain Cook's voyage in 1778 that the Seward Peninsula region was mapped and opened to European exploration and trade. Observations and extensive use of caribou products during this time is further evidence of the existence of a resident caribou herd on the Seward Peninsula. In late summer of 1778 Cook observed and noted caribou tracks on the beaches near Golovin and purchased freshly killed caribou meat from the local people (Ray, 1975). The Billings expedition of 1791 landed near present-day Nome during late summer and noted that caribou were plentiful, and skins of adults and calves were widely used for clothing and sleeping mats (Ray, 1975). Burch (n.d.:631-633), on the basis of interviews with Native elders, suggests that a caribou herd inhabited the central Seward Peninsula year-round before Europeans began settling in the area. The calving area was identified on the Espenberg Peninsula while the winter range extended throughout much of the central Seward Peninsula

The continued presence of Russian, American and European explorers and traders in the early 19th Century created ecological and socio-economic events that likely affected caribou populations on the Seward Peninsula. During the mid-1800s many whaling ships began to over-winter in protected areas such as Point Hope, Port Clarence and Golovnin Bay to avoid having to push through the pack ice to reach the Chukchi Sea and Arctic Ocean in spring (Stern *et al.*, 1980). Establishing permanent settlements enabled the whalers to start the following whaling season much earlier than before.

During the winter months the whalers traded with Natives and hired them to supply meat to inhabitants of the settlements (Stern *et al.*, 1980). People that traditionally lived a nomadic hunting and gathering lifestyle began to settle year round at these prominent trading sites. Large amounts of European goods were being traded for furs in settlements along the Bering Sea coast (Stern *et al.*, 1980). Tools such as axes, large knives and firearms were especially coveted. Although it was illegal to sell firearms and ammunition to Native Americans in the early 1800s, firearms found their way into Inupiat hands as early as 1816 and were in use by the 1820s (Ray, 1975). There must have been an increased harvest on the local wildlife resources, notably caribou, to generate products (meat) for trade or sale to meet demands of a larger population, while the introduction of firearms allowed more effective harvesting of animals to meet this demand (Ray, 1975). By the late 1800s caribou and muskox were scarce or absent on the Seward Peninsula (Skoog, 1968). However, there may have been additional factors that spurred the disappearance of local caribou herds. Weather patterns, changes in forage availability or predation all may have played a role as well (Skoog, 1968; Adamczewski *et al.*, 1988; Caughley and Gunn, 1993; Messier, 1988).

Introduction of reindeer herding

The scarcity of large grazers during the late 1800s set the stage for transformation of the human/grazer relationship on the Seward Peninsula from sporadic, uncontrolled hunting to a managed animal production/rangeland system. Efforts to intensify the production of cattle and sheep were occurring in many western states of the U.S., but these animals were not compatible for use in the north. Sheldon Jackson, Commissioner

of Education in Alaska during the late 19th century, traveled to Chukotka and observed the reindeer herding economies of the Chukchi. Reindeer are domestic livestock that are well adapted to northern environments and have been used in pastoralist and animal production systems in Eurasia for thousands of years (Mirov, 1945) Different reindeer varieties were developed to suit local conditions and human needs. The Saami people of Norway used reindeer as a milk producing animal whereas the Samoyed and Vogul people of Siberia used reindeer primarily to draw sledges. In contrast, the Tungus of central Russia bred extremely tame reindeer to be used as pack and saddle animals (Dmitriez and Ernst, 1989). The Chukchi and Koryak people of present day Siberia developed their breed around 1000 AD in Chukotka and northeastern Yakutia (Dmitriez and Ernst, 1989). Their method of herding was conducted on foot, thereby selecting for animals with a strong herding instinct and weak migratory behavior. Chukotkan reindeer exhibit a high degree of site-fidelity even if local areas become overgrazed (Dmitriez and Ernst, 1989). This breed was further developed in Russia at state farms in Chukotka, Yakutia, and Kamchatka Peninsula to produce carcasses noted for their very fine muscle fibers and a high ratio of muscle tissue to bone (Dmitriez and Ernst, 1989).

Jackson is credited with the idea to introduce domestic reindeer to Alaska from Russia (Stern *et al.*, 1980). Jackson believed that vocational training delivered through missions was the most effective way of assimilating young Native Americans into the White world and reindeer herding was the best means of realizing this goal in Alaska (Ellanna and Sherrod, 2004). Jackson argued before Congress that the reindeer would provide a source of meat and economic development for the Inupiaq. The U.S.

government appropriated funds beginning in 1891 to purchase reindeer from Russia for importation to Alaska (Stern *et al.*, 1980). From 1892 to 1901, 1280 reindeer were purchased with government funds and transported to the Teller Reindeer Station at Port Clarence. Most reindeer purchased were Chukchi stock from the Cape Navarin area but reindeer were also imported from the Tungus of eastern Siberia in 1901 (Ellanna and Sherrod, 2004).

By 1896, 1300 reindeer were distributed among four herds in Wales, Teller, Brevig Mission, and Golovnin Bay. Jackson employed four Chukchi herders in 1893 to train the Inupiaq in handling and herding but friction between the groups resulted in the Chukchi herders return to Siberia (Stern *et al.*, 1980). In 1894, Saami herders from Norway and Finland were brought to the Seward Peninsula to teach reindeer husbandry to the Inupiaq. An apprenticeship program structured according to Jackson's image of an industrial school was developed under Saami instruction through local missions. Under the program, an apprentice would earn two reindeer the first year, five the second and ten for the third and each year thereafter (Olson, 1969). In contrast, the Saami instructors were given 100 reindeer for three to five years of service (Ellanna and Sherrod, 2004). In 1896 Jackson changed the apprenticeship program to five years with no reindeer to be earned during the period of instruction and with no guarantee of being loaned reindeer to establish their own herds. An Inupiat owner could only slaughter males for his family and could only sell, transfer or slaughter female reindeer with permission of the Board of Education. Also, upon an Inupiat owner's death, half of the herd would return to the mission instead of his heirs (Ellanna and Sherrod, 2004; Stern *et al.*, 1980).

This pattern ran counter to the U.S. government's intentions of Inupiaq ownership and in 1905 the Secretary of the Interior called for an investigation into allegations of Jackson's use of government funds to support missionary work and his policies on mission, non-native and Inupiaq ownership of reindeer. As a result of the investigation, Jackson was asked to resign and there was an ensuing effort to place as many reindeer into Inupiaq ownership as possible (Stern *et al.*, 1980).

The ownership pattern shifted to predominately native by 1914 but many of the owners had so few animals that their herds could not be considered economically viable. Also, many Saami owners had visions of developing extensive herds comparable to those in Scandinavia. Non-natives continued to develop their herds commercially in open conflict with native interests and government policies (Postell, 1990). The distribution of reindeer among so many Inupiaq did not increase the economic viability of reindeer herding. In light of this difficulty, the federal government suggested that Alaska Native owners form cooperatives or corporate herd ownership and standardize management practices. Under the joint stock ownership system all the animals owned by the people of one village were herded together by paid herders under the supervision of a chief herder. Herd cooperatives advocated open herding based on the Great Plains ranching model where there were no closed, formal, or privatized grazing allotments. Herders were encouraged to move their animals across the landscape in search of the best grazing areas. Many herders at the time were already finding it difficult to keep growing herds separated on adjoining ranges, and welcomed the open herding method (Postell, 1990;

Ellanna and Sherrod, 2004). This arrangement worked well for a short time, and reindeer herds grew in size while interest in joint stock companies was high (Postell, 1990).

The period of intense non-Native ownership of reindeer began in 1914 when John Silma, a Saami reindeer owner, sold 1200 reindeer to the Lomen family. Concerns about non-native ownership grew during the following years when the missions and other non-native owners began selling their reindeer to the Lomens. (Ellanna and Sherrod, 2004; Postell, 1990). The Lomens owned 14,083 reindeer by 1929 and established an extensive commercial export enterprise. (Stern *et al.*, 1980). The open herding method promoted a practice used by the Lomens to acquire "maverick" reindeer. The Lomens would move their herds into an adjoining herd and subsequently drive all animals within the area into a corral where all unmarked deer were marked to the person (Lomens) who drove them into the corral. The Lomens would also charge a herding fee for any Inupiat reindeer found in their herds. Even so, the Lomens were not able to make reindeer herding a business success, in part because of the difficulty in maintaining markets outside Alaska and the poor economic environment created by the Great Depression. They also could not stem the ever-present controversy over non-Native ownership, which finally ended with the passage of The Reindeer Act in 1937 which prohibited ownership of reindeer in Alaska by non-Natives (Ellanna and Sherrod, 2004). Cattle ranchers in the "Lower 48" also lobbied for passage of the Act because they felt threatened by the reindeer industry during a period of economic depression (Beach, 1985).

During the late 1920s and early 30s it was estimated there were approximately 600,000 reindeer in Alaska with 130,000 present on the Seward Peninsula (Stern *et al.*,

1980). Management of the herds consisted of allowing reindeer to graze freely across the Seward Peninsula in an "open range" system with no rotational grazing plans or regard for conservation of forage, particularly lichen. Lichen communities across the Seward Peninsula were greatly depleted during this time (Stern *et al.*, 1980) and given the slow annual production of lichen biomass recovery from overgrazing by reindeer (Kumpula *et al.*, 2000) likely influenced the productivity of reindeer herds for decades. However, during this time period the government continued to play a strong role in promoting and managing the Inupiaq reindeer herds. The government changed earmarks, representing ownership, from individuals to cooperative herds, recommended the adoption of close herding and the construction of corrals and more thorough roundups. Many of these recommendations were never acted upon because of the lack of leadership, confusion over animal ownership and revenue sharing and overgrazing caused by the high reindeer densities (Olson, 1969). The cessation of close herding, overgrazing of lichen, predation and reindeer losses to caribou may all have contributed to a sharp decline in reindeer numbers on the Seward Peninsula from a peak of approximately 130,000 animals in 1927, to 25,000 in 1950 (Stern *et al.*, 1980).

Modern reindeer herding: transition to rangeland management

The Bureau of Indian Affairs (BIA) took over administration of the Alaskan reindeer operation in 1941 and initiated a program to privatize and improve reindeer management on the Seward Peninsula (Stern *et al.*, 1980). The re-privatization of herds involved the establishment of a limited number of moderately stocked reindeer ranges

(Simon, 1998). Individuals were granted exclusive grazing rights of a defined area (referred hereafter as a range) provided a formalized management plan was followed. Seventeen new herds were started on Seward Peninsula reindeer ranges. By 1948, herds contained an average of 1000 reindeer each. A program was developed to introduce intensive herding, where herders would travel with the herds on a constant basis and continuously move them to new grazing areas. BIA also attempted to improve methods of handling and slaughtering, and to base stocking densities on available winter forage (Stern *et al.*, 1980).

The period of re-privatization and establishment of new herds resulted in a relatively stable industry where herd numbers and product output remained constant. The primary market during this period was local, but government sales within Alaska and to the 'lower 48' were also important (Olson, 1969). In 1968, in a cooperative agreement with the State of Alaska, the BIA and the Bureau of Land Management (BLM), the latter agency undertook the supervision of the ranges (Stern *et al.*, 1980). This had important implications for future grazing policy because it laid the groundwork for formal range management planning as practiced on other public rangeland in the U.S.

The BLM began issuing reindeer grazing permits in 1962, and in 1968 was made responsible for assessing and protecting rangelands by performing range utilization checks and setting stocking densities throughout the 4 million hectares of reindeer range (Stern et al., 1980). To be granted a grazing permit on State or BLM land, the herder must develop a grazing management plan in cooperation with the Soil Conservation Service (SCS) which is presently called the Natural Resources Conservation Service

(NRCS), (SCS, 1953). NRCS has specific responsibility to assist permittees of grazing lands in planning and applying conservation programs on the federal controlled land in their operating units using the National Range and Pasture Handbook (NRPH) as a guide. This plan recommends the sustained yield of the herd with no detrimental changes to the range as a result of grazing reindeer (National Range and Pasture Handbook, 1997).

Since the 1970s, reindeer herding has been a significant economic factor in villages on the Seward Peninsula (Schneider *et al.*, 2005). While the development of the reindeer velvet antler market during the 1970s and 80s enhanced profitability, most herders believe that meat sales provide the economic backbone for the industry and manage their herds accordingly. All present-day herders castrate excess males to reach a ratio of one reproductive male for every 15 to 20 females in their herds. Although velvet antler sales generated $10.3 million U.S while reindeer meat sales generated $9.6 million U.S. from 1987 to 2003 (Brown, 1987-2003 Alaska Agriculture Statistics), herders still believe development of the meat industry is key to their long-term economic success.

The management structure of the Seward Peninsula reindeer industry at present is very different than those found in Scandinavian countries or Russia largely because of the adoption of permitted grazing. Individuals or families are given exclusive grazing rights on designated ranges averaging 400,000 hectares in size. Land managers and reindeer herders work together to develop a range management plan and set maximum stocking densities. State and Federal land managers also monitor range conditions and make recommendations to the herder on changing grazing areas. In this way the herder is encouraged to manage his reindeer and grazing resources to generate income without

overgrazing the rangeland. Currently, most herders practice an extensive management style of herding. The herds are left unattended for parts of the year, although many herders actively check their herds during winter when snow and weather conditions allow travel. Some herders will move their animals between winter and summer ranges and calving sites, while others may move their herds to a new grazing area during winter to avoid overgrazing of lichen areas or reduce mortality to predation. During the snow-free months from June through September, reindeer are allowed to freely range on identified summer grazing areas. The herder, while not in contact with the reindeer, usually knows the general location of the herd from pilot reports, other travelers or, occasionally, he will travel by boat, plane or all terrain vehicle (ATV) to check the herd. Reindeer are typically brought into corrals twice a year: During June-July for marking of calves, vaccinations and other veterinary services, as well as harvesting of velvet antler, and in mid-winter again for veterinary care. Most of the slaughter is conducted when snow covers the ground, but some may be done anytime during the year to accommodate economic necessity. Though herders do not practice strict selective breeding, most of the males are castrated and unproductive females are culled based on physical or production characteristics. Animals are driven into corrals using snow-machines during winter, and helicopters or ATVs during summer. Helicopters are usually used by herders owning large herds where smaller herd owners find helicopter use too expensive. Also, a herder decisions whether to use a helicopter or not is influenced by the price paid for velvet antler. A higher return per unit herding dollar spent lessens the chance of losing money if only a small number of animals are corralled. Reindeer demographics and ear tag

numbers are collected at handlings by technicians and total number of reindeer corralled annually is estimated for each herd and archived at the Reindeer Research Program, University of Alaska Fairbanks (RRP-UAF).

Snow-machines were adopted in the early 1970s (Stern *et al.*, 1980) and used both in summer and winter. This mode of travel enabled herders to travel great distances in a short time allowing herding to be based out of villages rather than outcamps. This type of management allowed reindeer herders to spend time with their families who were socially tied to the village because of schooling and supplementary family employment. Extensive herding also allowed reindeer herders the time and opportunity to become involved in regional and state politics. Many herders became active as corporate board members, village officers or state legislators.

The formation of the Reindeer Herder's Association (RHA) in 1971 by the BIA united the herders in their efforts to further develop the reindeer industry (Bader and Finstad, 1999). RHA established a five-year reindeer industry development plan in 1979 that would set guidelines to build an industry that would provide a stable meat supply and an enhanced economic base to the people of northwest Alaska (Stern *et al.*, 1980). Foremost objectives of the plan were conducting and inventorying range resources and developing and adopting sustainable range management practices recommended by NRCS. Reindeer herders repeatedly acknowledge that good rangeland management is critical for the present and future success of the industry (RHA annual meeting minutes; 1999-2006).

Present day range management of reindeer

The most common type of rangeland tenure in the world is open, communal grazing with a nomadic or transhumanance pattern of animal management. Nomadic herders or pastoralists have no permanent base but move their livestock to areas of the most abundant forage. Transhumanance herders have a permanent base to which they return each year but move with their livestock during portions of the year. Reindeer grazing in Fennoscandia and Russia is either done in a pastoral or transhumanance manner on communal grazing areas. However, many people in the U.S. regarded communal grazing as one of the prime factors responsible for degradation of grazing lands due to overstocking and/or overgrazing. Hardin's (1968) "Tragedy of the Commons" went on to argue that selfish herders would maximize herd numbers to use range resources before their neighbors did. Rangeland, pasture, and forages together comprise about 55% of the total land surface of the United States, about 400 million hectares (NRCS, USDA, http://www.nrcs.usda.gov/technical/land/pubs). These lands represent the largest and most diverse land resources in the U.S. The functions of these lands are of increasing national importance as producers of food and fiber, watersheds and habitats for biologically diverse plants and animals. Given the economic and social importance of rangelands to the U.S. and a concern for their proper management, government officials developed a national rangeland management policy that advocated control over numbers and movement of grazing animals and monitored the effect of grazing and other disturbances on plant biomass production and species composition of plant communities (National Range and Pasture Handbook, 1997).

To standardize the management of rangeland across the U.S., public and private rangelands, including those in Alaska, were divided into quantifiable and interpretive units called "ecological sites". Ecological site descriptions replace the traditional range site descriptions that focused primarily on forage production in favor of ecological site descriptions that include geology, soils, climate, hydrology, physiographic features as well as forage production. They are used to stratify the landscape and organize ecological information for purposes of monitoring, assessment, and management of rangeland. An ecological site is distinctive kind of landscape unit with specific soil and physical characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances. Unlike vegetation classification, ecological site classification uses climate, soil, geomorphology, hydrology, and vegetation information to describe the ecological potential of land areas. A particular ecological site may feature several plant communities (described by vegetation classification) that occur over time and/or in response to management actions. The development of the vegetation, the soil, and the hydrology are all interrelated. Each is influenced by the others and influences the development of the others. Ecological Site Descriptions (ESD) are made for each ecological site and a recent memorandum of understanding between the NRCS, BLM, and U.S. Forest Service establishes ESD development as an interagency priority and established national standards and protocols for ESD development (NRCS, USDA, http://www.nrcs.usda.gov/technical/land/pubs).

Ecological Site Descriptions are developed using the following ecological parameters:

1) Soils with like properties that produce and support a characteristic plant community and respond similarly to management are grouped into the same ecological site. The factors of soil development are parent material, climate, living organisms, topography or landscape position, and time. These factors lead to soil development or degradation through the processes of loss, addition, translocation, and transformation. In the United States, ecological sites are connected to spatial data via soil map units of the National Cooperative Soil Survey. Classification of soils in ecological sites of the Seward Peninsula can be referenced in Soil Investigations of the Seward Peninsula Area, Alaska (Van Patten, 1990).

2) The development of the hydrology is influenced by development of the soil and plant community. An ecological site has a characteristic hydrology, particularly infiltration rates of water through soil and surface flow.

3) An ecological site has evolved a characteristic plant community (cool season, warm season, grassland, shrubland, sedge meadow) and amount of vegetation. They are differentiated one from another based on:

a) *Plant community composition.* A detailed species composition list is estimated for the historic climax plant community or naturalized plant community. A detailed species composition list is also developed for any other states or plant communities that are considered desired plant communities, and a similarity index calculation is made. Species are listed by group, common and scientific name. The major plant species in the

total plant community are listed and their relative annual production is estimated and expressed in pounds air-dry weight (pounds per acre per year).

b) *Ground cover and structure.* Ground cover (vertical view) is estimated as the percentage of material, other than bare ground, that protects the soil surface from being hit directly by a raindrop. This would include first contact with plant canopy cover, biological crust, litter, surface fragments, bedrock and water. Soil surface cover is the percentage of the soil surface actually occupied by vegetative basal cover, biological crusts, litter, surface fragments, water and bare ground.

c) *Structure of canopy cover.* Canopy cover is estimated as the percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. The average height and canopy cover for each level of vegetative stratification is estimated.

d) *Total annual production.* The total annual production of the ecological site expressed as median air-dry production is estimated for favorable, normal and unfavorable years. In areas where examples of the historic climax plant community are not available, the highest annual production in plant communities for which examples are presently available are estimated.

An example of an ESD for the Seward Peninsula can be found in Appendix A.

Ecologists and rangeland managers not only describe the rangeland using ESDs but also assess the impact of disturbance due to fire, grazing by livestock and wildlife and anthropogenic effects using the theories of succession and retrogression. The succession theory holds that more developed soils and more complex mixes of plants replace less developed soils and less complex mixes on the land. According to the theory, succession ultimately results in a plant community in equilibrium with the environment, particularly climate and soil. This is the "climax" plant community. Disturbance of this plant community for any reason causes it to retrogress to an earlier stage of development. Using the succession-retrogression method, rangeland can be described as being in "excellent," "good," "fair", or "poor" condition, depending on how closely the current composition and production of the vegetation on a site resemble the climax vegetation defined for the site. This method of determining rangeland condition was first used in the 1940s to help ranchers determine the value of their land for livestock grazing. This model worked well in the grassland region of the United States where climax vegetation was mostly made up of highly productive and nutritious grasses and forbs that also protected the soil from erosion. In the 1960s, range conservationists and scientists further developed this classification system to include ecological condition and values. Where the succession-retrogression model works, it is a powerful tool to explain and predict how rangelands change with use and management (NRCS, USDA, http://www.nrcs.usda.gov/).

However, the succession-retrogression method of evaluating rangeland condition has not worked so well to describe both ecological condition and value for livestock

grazing in other parts of the United States. Beginning in the late 1990s ecologists and rangeland managers developed state and transition models in explaining rangeland ecosystem change. State-and-transition models synthesize literature and informal knowledge tied to particular ecological sites to distinguish changes in vegetation and soils that are easily reversible versus changes that are subject to thresholds beyond which reversal is costly or impossible. The models describe all possible states, community phases (i.e., easily-reversible variants of states), and transitions between communities and states. Transitions contain information about mechanisms, triggers, thresholds, and indicators of threshold development. (NRCS, USDA, http://www.nrcs.usda.gov/).

A tremendous amount of work has been done since the 1990s on the implementation and evaluation of ESDs and state and transition models in a national grazing policy on rangelands of the contiguous 48 states using conventional livestock species. The tundra rangelands of the Seward Peninsula were inventoried and included in the national rangeland management program in the mid 1980s (Swanson *et al.*, 1985). Although NRCS and BLM have been working closely with reindeer producers in Alaska to implement national range management policy, producers are often critical of these efforts because the ecologists and range managers were educated and trained outside of Alaska and "know cows but they don't know reindeer". Reindeer producers in turn, do not have a clear picture of and have not fully implemented the management of their rangelands using ESDs. Since producers using public lands are mandated by land management policy to use ESDs in the management of their livestock, I will attempt in this project to adapt ESDs to better fit the current management strategies practiced by

reindeer producers on the Seward Peninsula. Also, ESDs are a circumscribed unit arbitrarily placed on the landscape which may or may not be compatible with reindeer foraging ecology. I intend to test hypotheses that evaluate the scale or units that best describe the interaction of reindeer with the environment. My purpose is to develop new interpretations of the animal/landscape interaction that may be used by land managers and reindeer producers to appropriately manage the range resources and use by reindeer.

First, in this chapter, I give a brief overview of the climate, soils and vegetation of the Seward Peninsula to introduce the components of the grazing system. Alaskan soils, climate and vegetation are very different from those of lower latitude grazing systems. The presence of permafrost, poorly developed soils and the short, but intense, growth pulse of plants during summer are just some of the unique characteristics of Alaska's tundra rangelands.

Although the NRCS has classified and mapped the vegetation according to ecological site we know very little about the nutritional value of this vegetation. The type of vegetation and its concentration of nutrients and cell wall components govern the productivity of a rangeland. In any given grazing system the nutrient concentrations of forage species fluctuate throughout the year. These fluctuations are driven by a number of environmental variables with moisture, solar radiation and temperature being the most dominant (Chapin, 1983). When favorable conditions arise a distinct wave of vegetative growth will begin, the plants will mature, then senesce in a distinct pattern across the landscape that will determine the nutrition and productivity of forage plants within an ecological site.

Chapter 2 describes the nutritional profile of forage plants consumed by reindeer on the Seward Peninsula. Range management is geared to vegetation communities as a whole. However, community responses are controlled by responses of individual plants. Consequently, an understanding of the broad range of forage nutrients at the landscape (range) level is needed to devise effective range management strategies for reindeer. To comprehend the collective effects of a dynamic forage base and to place reindeer in the best grazing area is a daunting task for a herder but can best be visualized and implemented using maps. I have integrated the nutritional data with the ecological site productivity data to develop an interactive mapping program to identify grazing areas with the highest concentrations of nutrients during a designated day of the growing season. Thus, a nutritional atlas can be generated for individual ranges to be used by land managers and herders to visualize forage nutrient patterns developing across the landscape and to respond by moving animals to areas offering the best quality forage.

We have fairly good knowledge of the diets of *Rangifer* but the species composition of vegetation on the Seward Peninsula reindeer ranges is unique because of the interaction between the climate, soils and topography. Range managers and reindeer producers must know the seasonal diet composition of reindeer on the Seward Peninsula to identify ecological sites offering preferred forage species. Also, what are the implications for reindeer consuming different diets on disparate ranges; can we attribute differences in physiological measures or productivity to nuances of diet? Chapter 3 describes the seasonal diets of reindeer across individual ranges and the effects upon mineral values of blood and tissue and productivity of animals.

The timing and amount of protein in a ruminant's diet has an overwhelming effect on individual animal performance, reproduction and herd productivity. In Chapter 4 examine the nitrogen (N) sources in the diet using stable isotopes of nitrogen. I tested hypotheses relating ES composition of ranges is to diet, protein assimilation and, in turn, animal productivity. This knowledge will help producers identify the landscape units responsible for providing the N for their commercial protein products; meat and velvet antler.

The physical environment has a profound influence on the grazing environment. Although a producer makes assumptions about the gross productive potential of his range the weather will ultimately temper what he actually nets. Chapter 5 presents field data and a model that explores the impact of weather parameters on nutritional characteristics and accessibility of forage and consequences for animal production.

This dissertation is intended to benefit reindeer producers on the Seward Peninsula and is written as such. I have included expanded introductions and discussions and a plentitude of figures and tables in each chapter. I have also included additional material in the Appendix to aid the reindeer producer in applying facets of this study to current reindeer range management.

Physical characteristics of the Seward Peninsula grazing system

One of the most unique characteristics of the Seward Peninsula is the diversity of physiographic features and habitats exemplified in the 39 ESDs used to describe the grazing system (Swanson *et al.*, 1985). This heterogeneity, in turn, defines the grazing

environment for reindeer by both imposing constraints on acquiring nutrition during severe winter conditions and a short growing season, and providing opportunities such as a wide selection of high-quality forage species. The topography consists of extensive uplands of broad rounded hills and flat divides, 150 to 600m high, intersected by sharp V – shaped drainages. Isolated groups of rugged glaciated mountains 800 to 1400m in elevation surround low-lying interior basins to create an array of regional climatic zones. The bedrock is mainly metamorphic with massive granitic intrusions. Acidic volcanic rock in some areas and limestone uplands in others support distinctive vegetation communities. Clusters of pingos and thermokarst lakes are common in interior lowlands dominated by large rivers such as the Buckland and Koyuk, while periglacial processes and polygon formation dominate other lowland areas. A coastal plain dominated by wet sedge meadows and beaches forms the perimeter of the peninsula (United States Geological Survey, 2006).

The surrounding Bering Sea largely influences the plant life found on the Seward Peninsula. Maritime tundra is the dominate biome created by the wet, cool and windy conditions. A gradual transition from maritime to arctic tundra occurs northward across the Seward Peninsula from Nome to Kotzebue Sound and also from maritime to alpine tundra in mountainous regions.

Climate

Climate is the main external factor influencing the composition and functions of the Seward Peninsula grazing system and is characterized by cool, wet, short summers with continuous daylight; cold winters with near continuous darkness, and snow-cover

from November to late May or early June. The climate, although maritime, can be considered transitional because drier and colder continental conditions may occur up to 8 months of the year when the surrounding sea is ice covered. Average January temperature is -16^{O} C and mean July temperatures are usually below 10^{O} C. The average daily minimum temperature in summer is 1 to 6^{O} C while average maximum is 13 to 17^{O} C. The mean winter minimum temperatures are –24 to –19^{O} C with a mean daily maximum of -16 to -11^{O} C. Average annual precipitation, including snow, is 35 to 46 cm but may be higher in coastal areas. Average snowfall is highly variable but averages 1 to 2 m per year.

In summer, because days are so long, the annual input of solar energy is approximately the same as western U.S. rangelands. But because much of the surface of the Seward Peninsula is snow-covered or water saturated and highly reflective, a smaller percentage of the available energy actually remains to heat the surface (LeDrew and Weller, 1978). Coastal areas experience frequent summer cloudiness that reduces incoming solar radiation by 50% or more (Weller and Holmgren, 1974). Radiation is maximal in late May and June when foliar tissue of plants is just emerging and decreases after green-up is complete and leaves have reached maximum leaf area. Air temperatures during the growing season are low and frosts or snow-fall may occur at any time. The growing season defined here as the time that plants are snow-free and thawed is approximately 100 to 114 days, but, is highly variable from year to year (Myers and Pitelka, 1979).

The climate on the Seward Peninsula land mass is greatly influenced by the

surrounding Bering Sea. Local onshore and offshore winds, low clouds, and fog occur frequently in summer, as do snow-fall in spring and fall. High land masses act as a barrier to moist air that might otherwise penetrate from the Bering Sea causing inland areas to receive less precipitation. The leeward slopes also receive considerably more precipitation as snow is deposited from windswept areas.

Wind is a significant factor influencing vegetation and animal disposition. Winds are prevalent with some coastal areas, such as Teller and Wales, particularly windy (mean annual daily wind speed 7 to 9.4 m s^{-1}). These strong winds prevent tree growth in areas that may have suitable temperature and soil conditions. Branches of shrubs that extend above snow during winter exhibit a high degree of winter kill due to abrasion (Bliss, 1962). Wind is also effective at reducing leaf temperature which promotes the development of prostrate plants (Bliss, 1960). High winds during winter pick up snow and reduce particle size that is redeposited in dense "sastrugi" drifts (Rattenbury, 2006)

Soils

The Seward Peninsula soils are generally poorly drained and shallow and classified as Histic Pergelic Craquepts, Pergelic Cryaquepts, Typic Cryochrepts, Pergelic Cryumbrepts, Lithic Cryorthents, and Pergelic Cryorthents (Van Patten, 1990). On the tops and upper slopes of hills and mountains frequent freezing and thawing fractures the underlying rocks. The fractures normally occur at right angles to each other. This mechanical weathering creates large areas of rocky soils. The fine materials and the smaller rocks are washed downhill by flowing water and by gravity creating a patchwork of soil with varied properties across lowland and upland areas. The lowland soils are

waterlogged and acidic and do not show full development because they are subject to annual stirring or mixing caused by frequent freezing and thawing. The churning of the active layer creates a patchwork of soil moisture, nutrients and stability which results in a diversity of vegetation microhabitats. Species of plants well adapted to the varying degrees of frost action lead to the eventual development of diverse, but stable vegetation communities. These communities provide the framework for management of the Seward Peninsula as rangeland.

Other than climate the most important feature in terms of soil development and influence on vegetation is the presence of permafrost. The depth of thaw during summer, termed the active layer, may be only half a meter or less. The consequence is that the surface water does not move downward in the soil but instead is concentrated near the surface. This results in what is known as perched water table, and causes much of the landscape to be waterlogged, though annual precipitation is relatively low (Walker and Harris, 1976). The poorly developed soil horizons and thin active layer cause plant root systems to be very shallow (Bliss, 1962). Changes in temperature and snow cover or disturbance to the active layer may cause underlying permafrost to thaw, improving drainage of the upper soil layer. Dryer soils are warmer and more likely to support tall vegetation such as shrubs or trees. These variations in soil conditions give rise to stratification of vegetation communities and primary production (Bell and Bliss, 1978; Billings and Mooney, 1968).

During winter the soil in the active layer is completely frozen. Soil thaw proceeds immediately following snowmelt, but does not reach a maximum depth (20 to 100cm)

until September (Addison and Bliss, 1980: RRP unpublished data). In autumn, soils remain partially thawed and biological activity continues even after snowfall or freezing air temperatures. The freeze-thaw process increases concentrations of plant-available phosphate and ammonium in organic soils in spring and fall which influences the rooting and nutrient uptake strategy of different plant growth forms (Schimel *et al.*, 1995). Snowmelt usually begins in mid-May along the coastline and continues through June in upland areas. Snowmelt is rapid where run off occurs over the partially thawed soil surface in 3 to 10 days (National Weather Service data 1985 to 1999, Nome, Alaska acquired from the Natural Resource Conservation Service (NRCS), United States Department of Agriculture, Anchorage, Alaska). Consequently, there is a flush of nutrient availability in spring followed by large fluctuations throughout the rest of the summer (Chapin *et al.*, 1978; Hobbie and Chapin, 1996).

Nutrient availability for plant uptake is generally low because low temperatures inhibit chemical weathering of parent material and reduce rates of mineralization (Chapin *et al.*, 1978; Chapin, 1983), Nitrogen is available almost entirely as ammonium rather than nitrate but some plant species may use amino acids (Kielland, 1994). Although nutrient availability is generally low, it is highly heterogeneous with concentrations varying by an order of magnitude between adjacent microhabitats (Barél and Barsdate, 1978).

Vegetation

Although vegetation of the Seward Peninsula is considered tundra it is highly variable and not dominated by a particular plant growth form (Walker, 2003). Species

and growth form composition of communities can vary dramatically along regional and latitudinal gradients (Billings and Mooney, 1968; Wielgolaski, 1975). Vegetation communities may be dominated by shrubs, graminoids or forbs; deciduous or evergreen vascular plants or moss and lichen (Bell and Bliss, 1977; Bliss, 1981; Wielgolaski, 1975). Heterogeneity is also increased through differences in morphology and physiology of growth forms of the same species as seen in *Carex aquatilus* (Chapin and Shaver, 1989).

Plant communities transition between maritime (wet) tundra along the coast to subarctic (dry) tundra inland to alpine tundra in the higher elevations (Swanson *et al.*, 1985). Shrub lands of willow and alder are well developed on low rolling hills in the southern Seward Peninsula while the same terrain to the north supports mainly tussock tundra. Various willow species dominate the extensive riparian zones that finger across the Seward Peninsula. Low shrubs such as *Vaccinium, Ledum* and *Betula* are common in well drained upland-heath areas (Swanson *et al.*, 1985), but alder (*Alnus crispa*) is found in areas with higher soil moisture, particularly on the lee side of hills where snow often drifts and accumulates. Tussock-forming *Eriophorum vaginatum* is a graminoid found across much of the Seward Peninsula, but in warmer areas is replaced by the tussock-forming sedge *Carex bigelowii. Carex aquatilus* is the dominant graminoid found in drainageways while *Eriophorun angustifolium* and *Carex lyngbaei* are semi-emergent sedges commonly found along the edges of sloughs, ponds and lakes. Forbs such as *Pedicularis spp.*, *Hedysarum alpinum* and *Equisetum spp.* are found across ecological sites, from lowlands to the tops of mountains.

There are a number of large, low lying river deltas influenced by diurnal tides or

storm surges. Meadows which are occasionally flooded by the sea are dominated by sedge and graminoid species such as *Carex ramenski, Carex lyngbaei* and *Eriophorum angustifolium* that are commonly eaten by reindeer (See Chapter 3).

Lichens do not have roots so they do not need to tap soil moisture like vascular plants, thus they can grow in locations impossible for most plants, such as bare rock, soil free of organic matter, or sand. Because of the nonexistent or poorly formed soils, lichens are common on the Seward Peninsula. The following lichen species consumed by reindeer on the Seward Peninsula are; *Cladina rangiferina, Cladina mitis, Cladina stellaris, Cladina arbuscula, Cladonia uncialis, Cetraria islandica, Cetraria nivalis* and *Cetraria cucullata* (Pegau, 1970). Thirty one ecological sites have at least 10 percent lichen cover while 14 ecological sites are lichen-dominated (50 or more percent lichen coverage), (Swanson *et al.*, 1985).

The entire year's production of leaves, stems, roots, and reproductive parts of vascular plants must take place during a very short growing season. The major factor controlling the onset of growth across the Seward Peninsula and among years is the timing of snowmelt and above-freezing temperatures. Green-up occurs shortly after snowmelt but the timing of growth of above versus belowground tissue is decoupled by many weeks. The optimal conditions for growth of leaves occur in late May and June when daily solar radiance is high but the soil and roots are still frozen solid. The rapid growth of leaves is supported by using carbon and nutrient reserves stored in above or belowground stems (Shaver and Billings, 1976; Chapin *et al.*, 1986; Chapin and Shaver, 1985). Many forage plants on the Seward Peninsula have high N concentrations because

they undergo a tremendous growth pulse which requires increased enzyme and N concentration for protein synthesis (Klein, 1970); (See Chapter 2). High rates of protein synthesis also requires increased carbon which may be limited because fixation is constrained by the short growing season and cool ambient temperatures caused by overcast conditions. Forage quality is increased because little carbon is available for synthesis of digestibility inhibiting structural fiber.

The timing of leaf growth often varies among the major plant growth forms (see Chapter 2). *Eriophorum vaginatum* and *Carex bigelowii* grow in dense, erect tussocks providing a warm and favorable microclimate during snow-melt. Inflorescences and leaves emerge from snow cover earlier than the lower inter-tussock areas and provide critical nutrition for reindeer during this time (Kuropat and Bryant, 1983). Root growth begins as soils thaw and occurs anytime from 1 to 6 weeks after the snow-cover melts and mean air temperature rises above freezing (Shaver and Billings, 1975; Kummerow *et al.*, 1983). Roots of different graminoid species grow under characteristic timetables (Shaver and Billings, 1975). Root tips of some sedge species like *Carex bigelowii* start the season near the surface and follow the soil thaw line until mid-august (Schimel *et al.*, 1995). Perennial roots of *Carex aquatilus* overwinter to a depth of 10-25 cm and do not become active until they are thawed out in late June or early July (Schimel *et al.*, 1995) but stay green much later in fall than other sedges (author, pers. observation).

In general, willow species are found only in riparian and protected upland areas and where winter snow prevails. Shrub height is well correlated with mean winter snow depth (Billings and Bliss, 1956). Shrubs buried under winter snow are protected from

abrasion and desiccation caused by the severe winds and cold of the Seward Peninsula. Increased moisture from melting snowdrifts later in the growing season creates soil moisture conditions amenable to willow growth. Erect deciduous shrubs such as *Salix* and *Betula* species begin leaf expansion about two weeks later than graminoids (see Chapter 2). Regional patterns of leaf emergence also vary considerably across ranges in relation to climatic and topographic gradients (see Chapter 3).

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CHAPTER 2

Nutritional mapping of grazing areas using nutrient and fiber profiles of reindeer forage plants of the Seward Peninsula, Alaska

Abstract

Reindeer producers on the Seward Peninsula, Alaska must be able to recognize and predict the nutritional characteristics of their rangelands to place animals in areas of high quality forage during spring and summer to increase growth rates and calf production.

Models were developed using Julian date (JD), growing-degree-days (GDD) and phenology (PH) to predict concentrations of nitrogen (N), phosphorus (P), potassium (K), neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) of forage plants throughout the growing season found on reindeer ranges of the Seward Peninsula.

Profiles of mineral, fiber concentrations and digestibility differed greatly across plant growth forms, but were similar among members of the same genus. Nitrogen, P and K concentrations were very high in emerging leaves of willow and forbs and declined at a fluctuating rate through the growing season. Concentrations of nitrogen and minerals, and digestibility of leaves of graminoids and digestibility of willow leaves increased during spring to early summer when they began to decrease. NDF and ADF concentrations in graminoids were at a minimum during midseason, in contrast to deciduous shrubs that exhibited low fiber concentrations in the spring with progressive increases through midseason to senescence. Fiber concentrations in forbs were lower and fluctuated less

dramatically than either graminoids or shrubs. Digestibility of willows and graminoids was less than forbs.

A computer program was developed to generate a seasonal nutritional atlas by coupling these data with existing biomass production data to guide placement of reindeer on large, diverse ranges. Julian date was used as a general predictor of plant chemistry and indicator for reindeer placement, whereas the relationship between GDD and plant chemistry was used to refine animal location based on the unique thermal characteristics of specific sites. A reindeer producer can also use the stage of growth (PH) to evaluate the real time, nutritional status of forage across his range.

Key words: Forage quality, reindeer production, range management, nutrient concentration, digestibility, environmental variation, temperature, phenology.

Introduction

Across the circumpolar north tundra rangelands and grazing animals have been used by humans for thousands of years. Tundra grazing systems, while not particularly productive, are capable of sustaining relatively few species but large populations of mammalian grazers such as caribou/reindeer (*Rangifer*). Known human dependence on *Rangifer* has a long history dating back to the Middle Pleistocene (Banfield, 1961). In recent times, these animals have been important in North America for many Eskimo, Northern Athapaskan, and Northern Algonkian people and in Eurasia for Saami, Samoyed, Northern Tungus and Siberian peoples (Burch, 1972). It is not clear when and where reindeer were originally domesticated but many groups of people selectively bred and kept reindeer across the northern Eurasian continent in animal production systems for thousands of years (Mirov, 1945).

Different reindeer varieties (*Rangifer tarandus tarandus*) were developed across the Eurasian continent to suit local conditions and human needs. The Saami used reindeer as a milk producing animal where the Samoyed and Vogul people used reindeer primarily to draw sledges. In contrast, the Tungus people bred extremely tame reindeer used as pack and saddle animals. The Chukchi and Koryak people developed their breed around 1000 AD in Chukotka and northeastern Yakutia. Animals with a strong herding instinct and weak migratory behavior were selected for because their method of herding was conducted on foot. Chukotkan reindeer exhibit a high degree of site-fidelity even if local areas become overgrazed (Dmitriez and Ernst, 1989). The Chukotka breed is the most recent breed developed. They were selected as meat producers not as a milk-producing,

draft or pack animals. Chukotkan reindeer carcasses are noted for their very fine muscle fibers and a high ratio of muscle tissue to bone. The rate of lean tissue and fat deposition and percentage of carcass is higher than in other breeds which enable animals to survive long periods of poor foraging conditions during winter (Dmitriez and Ernst, 1989). On Chukotka and the Seward Peninsula, Alaska, calving peaks April 25 – May 1, 15-20 days earlier than in other breeds. Calves grow at a very high rate (Finstad and Prichard, 2000) and reaching maturity at a young age (Prichard *et al.*, 1999).

Chukotkan reindeer were introduced to the Seward Peninsula, Alaska from Russia in 1891 as a means for Alaskan Natives to develop an animal production system providing a predictable red meat supply and economic development. By 1896, 1200 reindeer were grazing on the Seward Peninsula distributed in four herds. The vegetation communities encountered by foraging reindeer must have provided good nutrition because by 1924 the population had risen to 130,000 animals (Stern *et al.*, 1980). Lichen on the Seward Peninsula ranges, which is the primary winter forage of reindeer and is often a limiting factor for reindeer production, was likely overgrazed during this time period and may have contributed to the decline of reindeer numbers by the 1940s (Stern *et al.*, 1980).

The management of Alaskan reindeer has varied dramatically since the 1920s; however they continue to be a significant driver of economic development in rural Northwest Alaska. In 1944 the Bureau of Indian Affairs (BIA) assumed administration of the Alaskan reindeer operation and initiated a program to privatize and improve reindeer management on the Seward Peninsula (Stern *et al.*, 1980). A plan was developed to set

up 19 reindeer grazing permit areas in large designated ranges, consisting of state and federal lands, and to introduce intensive herding and improve methods of handling and slaughtering (Fig. 2.1), (Stern *et al.,* 1980). In 1971 the reindeer producers organized into the Reindeer Herder's Association (RHA) and initiated a plan to standardize and improve range management practices (Bader and Finstad, 2001).

RHA requested the Alaska Soil & Water Conservation District and the United States Department of Agriculture, Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS), for assistance in developing range management plans for reindeer. Range management plans would identify seasonal grazing areas and make recommendations on placement and distribution of reindeer and stocking density. In response, the NRCS initiated a plan to conduct a vegetation inventory and mapping of the 6 million hectares of permitted rangeland on the Seward Peninsula. Plan objectives were to: identify, map and describe "ecological sites"; describe plant community characteristics of each ecological site; quantify plant communities in terms of species composition and annual productivity; and collect other information for resource planning on Seward Peninsula rangelands (National Range and Pasture Handbook. 1997).

Vegetation of the Seward Peninsula is classified as tundra. A diversity of land features and micro-climatic zones create a mosaic of environments and vegetation types ranging from high elevation alpine tundra to tidal-influenced marshlands (Swanson *et al.* 1985). Thus, the landscape is dominated by an assortment of communities made up of graminoid, shrub, forb and lichen species. NRCS inventoried the vegetation and developed digitized maps of thirty-nine ecological sites found across the Seward

Peninsula (Fig. 2.2). In each ecological site soil hydrology, plant species composition and cover, annual plant productivity and biomass were described (Appendix A), (Swanson *et al.*, 1985).

Whereas the inventory and mapping of forage are critical to development of range management plans for the Seward Peninsula, the nutritional dynamics of plant species making up ecological sites must be known by the producer to support management decisions that ensure or increase production of his livestock. However, the nutritional characteristics of most reindeer forage plants on the Seward Peninsula are unknown. Under extensive grazing, nutrition of reindeer is not only influenced by the amount of forage but by the simultaneous concentration of critical nutrients and ratios of cell wall components. Many reindeer producers allow their animals to range freely for most of the year but do move animals to specified areas for calving and summer and winter grazing. Recently, there has been a transition to more intensive range management because producers wish to increase meat and velvet antler production and reduce herd loss due to the Western Arctic Caribou Herd (WACH) that has shifted its winter range onto the Seward Peninsula reindeer ranges (Finstad *et al.*, 2008).

Three plant characteristics: fiber content, mineral concentrations and digestibility are usually regarded as the principle factors that determine feed quality for ruminants. Comparatively small differences in the proportion of these components can markedly influence weight gain in reindeer (McEwan and Whitehead 1970, White 1983). Plant species and phenological stage of growth are usually regarded as the primary factors influencing the concentration of nutrients and fiber in green vascular plants available as

forage to reindeer (Klein, 1990; Van Soest, 1994). Forage plants found in tundra ecological sites must emerge, mature, acquire and store nutrients and energy in a very short growing season often in the midst of highly variable snowmelt and temperature patterns. Environmental patterns will affect the timing of individual growth events, both within and among species and ultimately influence the nutritional characteristics of forage for reindeer at any given time (Chapin *et al.*, 1986a; Chapin *et al.*, 1986b; Chapin, 1987; Larigauderie and Kummmerow, 1991; Galen & Stanton, 1995).

Reindeer on the Seward Peninsula exhibit fast growth rates (0.43 kg day^{-1} for male, 0.37 kg day^{-1} for female calves) during summer and achieve a high body mass (98 kg for females in winter) and high reproductive rates (up to 39% yearling females lactating) compared to other circumpolar *Rangifer* populations (Prichard *et al.*, 1999; Finstad and Prichard, 2000). Thus, they have high demands for nitrogen (N), potassium (K) and phosphorus (P) when nutritional characteristics of the forage base are diverse and ephemeral. Thus, being in the right place at the right time is very critical for productivity (Klein, 1990; Pullianen, 1971; Skogland, 1975; Staaland and Saebo, 1993). Alaskan reindeer demonstrate sedentary behavior with strong site fidelity so they may not be inclined to migrate to alternate grazing areas within an allotted range. Reindeer producers, in turn, must recognize the dynamic nature of the changing chemistry of forage plants on their ranges to implement seasonal rotational grazing strategies or placement of their animals in areas to maximize nutrition. To comprehend the complex effects of a dynamic forage base and to place reindeer in the best grazing area is a daunting task for a producer but can best be visualized and implemented using maps. By

generating and integrating seasonal nutritional profiles of forage plants with ecological site production data, an interactive mapping program can be developed to identify grazing areas with the highest concentrations of nutrients during a designated day of the growing season. Thus, a nutritional atlas can be generated for individual ranges to be used by land managers and herders to visualize forage nutritional dynamics across ranges. Then they can develop management plans or to place animals in areas containing the most nutritious forage.

A reindeer producer can develop a grazing management plan based on predicted nutritional characteristics of grazing areas, but the environment, in particular temperature, is variable across the landscape and from year to year. He may want to adjust his grazing rotation knowing similar areas of his range warm up or green-up faster or are cooler than others because temperature can have a profound effect upon plant chemistry (Deinum 1984, Bennet and Mathias 1984; Van Soest, 1994). He must also be able to assess the relative quality of his chosen grazing area versus alternative locations on his range in order to make adjustments in animal distributions. Phenology (PH) or stage of maturity is a common means to describe quality of agricultural forages (Van Soest, 1994). A predictive model of forage nutrition based on PH may be developed for plant species found on the Seward Peninsula that can be used by the producer in an on-site, real time evaluation of his nutritional management decisions.

I hypothesized that distinctive plant communities making up individual ranges give rise to heterogeneous patches of forage quality across the landscape. Furthermore,

nutrient characteristics of forage within these patches fluctuate through the growing season.

Objectives

The objective of this study was to evaluate the effect of species, maturity (phenology), season (date) and environment (temperature) on fiber and mineral concentrations in plants found in ecological sites of the Seward Peninsula. The seasonal nutritional profiles of forage plants were integrated with annual production data in an interactive mapping software program to construct a nutritional atlas (maps). These maps showing temporal and spatial forage quality of ecological sites can be used to identify desirable areas or regions for grazing reindeer. The producer can use this nutritional atlas to develop a general seasonal grazing plan using species distribution and date as the predictor of forage emergence and quality. He can further refine placement of animals to areas containing the highest nutrient forage by monitoring and evaluating the phenology of forage plants across his range. Similar ecological sites, although categorized according to equivalent physiographic features, may have slight differences in thermal characteristics which will effect phenology and nutrient concentrations and fiber levels of forage.

Study Site

The Seward Peninsula, located in Northwestern Alaska, lies between 161° and 168 ° west longitude, and 64 ° and 66 ° 30′ north latitude (Fig. 2.1). The peninsula encompasses a diversity of land features and climatic zones, with elevations ranging from sea level to 2500 meters above sea level. Variety in elevation and topography create an

array of environments and vegetation types ranging from high elevation alpine tundra to tidal-influenced marshlands. Thirty-nine ecological sites have been described and mapped by the Natural Resources Conservation Service (Fig. 2.2). This study was conducted on four reindeer ranges extending from the southern tip of the Seward Peninsula, northward for 100 km (Fig. 2.1). The Gray range of 400,000 hectares consists of a large river drainage system which is dominated by a large outwash delta. Mountains and hills surround the delta forming a solar basin with warmer spring and summer temperatures than found on the surrounding uplands (RRP unpublished temperature data). Many small lakes, ponds, and creeks are present giving rise to abundant growth of emergent and semi-emergent vegetation. Riparian shrubs are common. The Davis range of 350,000 hectares extends from sea level near Nome, northeast 80 km to the base of the Kigluaik Mountains, 1000 to 1500 m peaks rising above the rolling uplands of the Davis range. The uplands consist of hills and mountains under 700 meters in elevation bisected by numerous river and creek drainages. Vegetation consists of tussock tundra in lower elevations, shrubs and forbs in drainages and mid-slopes, and lichen mat on upper slopes. The Noyakuk range of 350,000 hectares extends from the Kigluaik Mountains, north to Imruk Basin. Imruk Basin and the Kigluaik Mountains are the dominant topographical features of the landscape. The Kigluaik Mountains rise steeply from the surrounding topography and often influence the local weather patterns. Surrounded by mountains or uplands, Imruk Basin is a large, shallow water body with associated lowlands that creates a solar basin which is characterized by warmer summer temperatures than adjacent areas.

Vegetation consists of sedges and grasses in the lowlands, shrubs on the mid-slopes, progressing to lichen mat on the higher elevations.

The Olanna range of 250,000 hectares extends from the York Mountains to the Agiapuk River. Much of the range consists of barrens and upland tundra in the hills and tussock tundra in lowlands. There is some wet tundra surrounding Brevig Mission merging with dry tundra on lower slopes of hills and mountains to the north and east while upper slopes are bald limestone or barren. Climate is influenced by onshore winds from Grantley Harbor with cold persistent winds in winter with cool wet, foggy summers.

Methods

Many of the plant species found on the Seward Peninsula are not consumed by reindeer, thus they were not sampled. In a pilot study to identify and survey the species of forage consumed, groups of grazing reindeer were located across the Seward Peninsula from May through August 1995. Fresh feces were collected and pooled from 10 individual pellet groups at each location. The samples were sent to the Washington State Wildlife Habitat Laboratory for microhistological diet analysis. These data were used to identify plant species commonly consumed by reindeer on the Seward Peninsula during summer.

This study was conducted in 1996 and 1997 on the Davis, Gray, and Olanna ranges and the Davis and Noyakuk ranges in 1998. Three to four replicate sampling areas (ecological sites) that contained the highest proportion of species found in the diet analysis and identified by the herder as a commonly used reindeer grazing area were

selected on each range (Fig. 2.1). The mapping unit and code numbers of ecological sites selected were Mixed Shrub (32), Low Shrub (35), Shrub Meadow (41), and Sedge-Wet Meadow (52) (Appendix B.1) (Swanson *et al.*, 1985). Ten *Salix pulchra* and ten *Carex aquatilis* plants were randomly selected within the sampling area (ecological site). These plants were selected as index species because they are found in the species composition list of most ecological sites, are widely spread across the Seward Peninsula and were found in most reindeer fecal samples. Each plant was visibly marked at each site and all identified reindeer forage plants, graminoids, forbs and leaves of deciduous shrubs within a 3 meter radius of each marked plant made up the sampling unit. Ten to twenty grams wet weight of leaves and flowers of deciduous shrubs were collected. All above ground tissue of forbs and graminoids were harvested and parts segregated until ten to twenty grams wet weight of leaves and flowers were collected. Removal of the entire plant was done to eliminate any effect of repeated sampling on the same individual of smaller plants. Samples were collected every 3-10 days beginning May 1 (Julian date 121) or as leaves emerged until the third week in September (Julian date 264). Infloresences of *Eriophorum vaginatum* were collected from April 25 (Julian date 115) until July 22 (Julian date 203). Only live or senescing tissue (chlorophyll still present) was collected. The amount of biomass removed from each site was negligible over the course of the sampling period so no carry-over or cross-over effect of sampling was assumed for ensuing collections.

All samples were oven-dried for 48-72 hours at 60^{O} C and ground using a 20 mesh screen in a Wiley® mill. Neutral detergent fiber (NDF) and acid detergent fiber

(ADF) concentrations were determined sequentially using an Ankom® fiber analyzer (Vogel *et al.*, 1999) at the Forage Analysis Laboratory, the School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks. Hemicellulose concentrations were obtained by subtraction of ANKOM ADF from ANKOM NDF values. Nitrogen (N) and macromineral (K, P) concentrations were determined at the Plant and Soil Analysis Laboratory, University of Alaska Fairbanks, Palmer, Alaska. Nitrogen concentrations were obtained with a CHN 1000 Analyzer and K and P concentrations determined using a nitric-perloric digest and ICP 3000. In-vitro true dry matter digestibility (IVTDMD) was done at the Institute of Arctic Biology Nutritional Laboratory, University of Alaska Fairbanks in ANKOM bags using the method of Goering and Van Soest (1970) with the Tilley and Terry modification (1963). Rumen inoculum was obtained from two cannulated reindeer at the Large Animal Research Station, University of Alaska Fairbanks. The animals were fed a pelleted ration but supplemented daily for two weeks prior to collection with 300 grams dry matter containing 20% willow (spp.), 30% lichen (spp.) and 50% graminoids prior to prep the rumen with a "Seward Peninsula" reindeer diet to adjust microflora populations.

Phenology of the plants making up the pooled sample was recorded using the index in Table1 and the mean stage of growth determined. Since changes were occurring in nutrient concentrations of leaves while vegetative phenology (VPH) stalled during full leaf expansion, observable changes in reproductive phenology (RPH) was used to index these changes. Reproductive and vegetative phenology values were summed (VPH + RPH) to give an index of overall phenology throughout the entire growing season.

A temperature data logger (Hobo-temps™) was placed at each of the 14 sampling sites attached to a tripod or willow stem one meter above ground level. The ambient air temperature was recorded every four hours and mean daily temperature (MDT) above a threshold of 0^{O} C was calculated. MDT = $\sum \frac{T_1 + T_2 + ... + Tn}{n}$ where $T_n < 0^{O}$ C = 0^{O} C and T_n = temperatures recorded during 24 hour day. Growing degree days, (GDD) was determined for each site beginning April 1 through the end of September where

$$GDD = \sum_{i}^{n} MDTi, \text{ where } i = \text{April 1 and } n = \text{September 30} \qquad (2.1)$$

Data were analyzed using the generalized linear models procedure of Systat 7.0 (Systat Software Inc. 1997). General linear models predicting seasonal fiber and nutrient concentrations in reindeer forage plants were determined using JD, GDD, and PH as treatment factors and concentration of fiber and nutrients as effects. All models were considered significant at $p < 0.05$. If there was no significant linear model, the means and standard errors were included in the results table to estimate the mean fiber or nutrient concentration throughout the entire growing season. All models were tested for normality and residuals were plotted and inspected for addition of higher order variables in the model to best fit the data. If data were not normal they were $\log_n$ transformed and analyzed. Models were expressed in non transformed form in the tables. Some species did not occur in all ecological sites or were missing from an entire range. Only species that were found in the diet analysis and in at least one ecological site in each range were included in the analysis to ensure replicate sampling. These species included willows; *Salix pulchra* (Sapu), *Salix alexsensis* (Saal), *Salix lanata* (Sala), *Salix fuscences* (Safu),

graminoids; *Carex aquatilis* (Caaq), *Carex bigelowii* (Cabi), *Carex lyngbyaei* (Caly), *Eriophorum angustifolium* (Eran), *Eriophorum vaginatum* inflorescences (Erva), *Arctophila fulva* (Arfu), *Calamagrostis Canadensis* (Caca), and forbs; *Equisetum arvense* (Eqar), *Equisetum fluviatile* (Eqfl), *Hippuris vulgaris* (Hivu), *Epilobium angustifolium* (Epan), *Pedicularis spp.* (Pesp).

The general linear models of nutrient concentrations of reindeer forage plants using JD, GDD and PH as continuous independent variables were coupled to forage biomass data by using proprietary software developed by the RRP to generate nutrient yield (pool size in kg) per ecological site. These data were ranked by kg of nutrient ha^{-1} and by using an online mapping program General Mapping Tools™ (GMT) the ranked ecological sites were color-coded and interactive maps were generated (See Appendix B). The mapping program was set up on a designated website for on-line use by producers http://reindeer.salrm.uaf.edu/).

Results

Leaves of *Salix* generally emerged at JD 150 over the three-year period (Fig. 2.3). Nitrogen concentrations in newly emerging leaves of *Salix* were very high but concentrations declined quickly, stabilized for 10-15 days at full leaf expansion then, began to decline again at approximately 1000 GDD (~JD 200) until senescence (Figs. 2.4, 2.5). NDF and ADF concentrations increased over the course of the growing season in a curvilinear manner (Table 2.2). IVTDMD increased soon after emergence, peaked at approximately 400 GDD and then declined throughout the growing season (Figs. 2.6, 2.7;

Table 2.2). Generally, all independent variables JD, GDD, PH were reasonably good at predicting nutritional characteristics of the forage plants. GDD and PH were good predictors of willow mineral concentrations accounting for 66% - 94% of the variation while JD accounted for 55% to 90% of the variation (Table 2.1). All models were significant ($p < 0.001$) and the relationship between the treatments and effects were curvilinear in most cases.

Leaves of graminoids generally emerged 5-10 days earlier than leaves of willow over the three-year period (Fig. 2.8) and JD, GDD, and PH were good predictors of mineral and fiber concentrations and digestibility (Tables 2.3, 2.4, 2.5, 2.6). Nitrogen, P and K concentrations of newly emerging graminoid leaves was lower than in newly emerging willow leaves but increased to concentrations similar to those found in willow leaves during full leaf expansion (Fig. 2.9; Tables 2.1, 2.3). Nitrogen, P, and K levels declined steadily to approximately 1000 GDD (JD 200) when the rate of decline increased (Fig. 2.10). NDF and ADF concentrations initially decreased until full leaf expansion when concentrations increased until senescence (Tables 2.4, 2.6). IVTDMD of graminoids followed an inverse relationship to NDF and ADF concentrations (Fig. 2.11). Digestibility increased early in the growing season until approximately 500 GDD and then began to decline steadily until senescence (Fig. 2.12). Digestibility and mineral concentrations were generally less in graminoids than in leaves of willows (Figs. 2.5, 2.7, 2.10, 2.12; Tables 2.1-6). Infloresecences of *Eriophorum vaginatum* emerged very early in spring, JD 115, and senesced by JD 200 (Fig. 2.13).

Leaves of forbs emerged later than leaves of graminoids but at approximately the same time as leaves of willows (Figs. 2.3, 2.8, 2.14). JD, GDD, and PH were generally good predictors of mineral and fiber concentrations and digestibility (Tables 2.7-2.11). Nitrogen profiles resembled that of willow leaves where concentrations were high in newly emerging leaves but declined rapidly until senescence (Figs. 2.15, 2.16). NDF and ADF concentrations were lower in newly emerging leaves but increased steadily throughout the growing season until senescence (Table 2.8, 2.11). IVTDMD of forbs followed an inverse relationship to NDF and ADF concentrations where digestibility was very high in newly emerged leaves and declined steadily to approximately 1000 GDD when digestibility began to decrease at an increasing rate until senescence (Fig. 2.18). Digestibility was generally higher for leaves of forbs than in either willow or graminoid leaves (Figs. 2.6, 2.11, 2.17). Plant growth forms allocated carbon into different cell wall components. Graminoids contained substantially more hemicellulose than either shrubs or forbs (Fig. 2.19). Hemicellulose is a fiber fraction found in lichens and vascular plants that is digestible and is found in relatively high proportions in diets of free-range reindeer (Aagnes *et al.*, 1995).

Cumulative amount of nitrogen, minerals and fiber (kg ha^{-1}) contained in all forage differed greatly among ecological sites, whereas pool sizes in some sites changed substantially through the growing season while others did not (Figs. 2.20, 2.21). Only 6 out of 39 ecological sites were plotted in the figures but one can see how difficult it would be to use these data to distribute animals when nutrient pool sizes in all the ecological sites throughout the growing season are expressed graphically. A method to

simultaneously interpret these data arithmetically and spatially would be to convert these data to a color coded (by nutrient gradient) map. General Mapping Tools (GMT) was used to integrate ecological site spatial data with quantitative nutritional data to generate a color-coded, nutrient map using JD, GDD, or PH as the continuous independent variable. Examples of the quantitative nutritional data of each ecological site using the equations in Table 2.1-2.11 and the interactive mapping program can be seen in Appendix B.

Discussion

Rangifer production in the circumpolar North is extremely important for people for subsistence and commercial use. The life history of reindeer, as other northern ungulates, has evolved to respond to forage availability and quality (Klein, 1970). Hair and tissue growth, parturition, lactation, and replenishment of body stores are completed during a very brief time when energy and nutrients are most available. The degrees of success attained in these functions are largely determined by comparatively small differences in the characteristics of the diet (McEwan and Whitehead 1970; White 1983; Klein, 1970; Hanley, 1997; Albon and Langvatn, 1992; Reimers, 1997).

In any given grazing system the nutrient and fiber concentrations in forage fluctuates throughout the year. Species, maturity and environment are generally regarded as the primary factors influencing forage quality for *Rangifer* (Albon and Langvatn, 1992; Leader-Williams and Ricketts, 1981; Leader-Williams and Ricketts, 1982; Klein, 1990; Van Soest, 1994; Staaland and Saebo, 1993; White and Trudell, 1980) because they influence the relative concentration of fiber, nitrogen and minerals in plant tissue.

This change in the nutritional profile is accentuated in the northern latitudes where plants must complete their growth during a very short, but intense, growing season.

The pattern of forage plant emergence during spring in this study varied across growth forms and within species during the growing season. *Eriophorum vaginatum* flowers emerged during early spring even without any appreciable accumulation of heat across the landscape (Fig. 2.13). As temperatures warmed, distinctive pulses of vegetative growth were initiated. Leaves of graminoids emerged first followed 10 to 15 days later by leaves of willows and forbs (Figs 2.3, 2.8, 2.14).

Not only did emergence differ among growth forms but the nutrient and fiber concentrations found in leaves throughout the growing season differed as well. Many northern plants have high N concentrations because they undergo a tremendous growth pulse which requires increased enzyme and N concentration for protein synthesis (Klein, 1970; Chapin *et al.*, 1986a). Fluctuations in the proportion of cell content to cell wall components are influenced by carbon fixation rates and fiber formation during the growing season. Leaves of willows and forbs emerged with high concentrations of nitrogen and minerals but levels fell quickly after midsummer. Deciduous species move substantial quantities of nutrients into new leaves to support growth, but pool size declines rapidly because of growth dilution and the accumulation of fiber components (Chapin *et al.*, 1986b).

In contrast, graminoids emerged with relatively lower nutrient concentrations and digestibility, but levels increased to maximum levels by early summer. Many northern graminoid species retain leaves or stems over winter to support growth in early spring.

Nutrients are translocated to these leaves and stems after snow-melt, thus, cell wall concentrations can be high early and subsequently decline because of the accumulation of cell contents. Fiber concentrations rise again because carbon is fixed and deposited in cell wall components. Also, nutrients are exported from mature leaves to support root growth or into storage organs at this time which further increases the proportion of fiber components in graminoids (Deinum 1984; Chapin, 1987). The decrease in nitrogen, phosphorus and potassium concentrations may have occurred more gradually, and to a lesser degree, in graminoids than in willows and forbs because leaf emergence and growth proceeds throughout the season so that even late in the season some graminoid leaves have reasonably high nutrient concentrations (Tieszen, 1978).

The digestibility of newly emerging willow leaves increased until about 400 GDD even though fiber concentrations were increasing at this time. Newly emerged willow leaves contain high concentrations of anti-herbivory compounds, depressing early digestibility, but the concentrations decline as the leaves mature, likely due to dilution by growth (Pearl and Darling 1968; Palo, 1984).

Generally, all tundra growth forms allocate resources to leaves in early season, reversing the flow of nutrients to support growth of rhizomes, and roots when leaves reach maturity and the ground thaws (Bell and Bliss, 1978; Chapin *et al.*, 1986a, Chapin *et al.*, 1986b). Nutrient concentrations in leaves of most plants sampled decreased throughout the growing season, but at an increasing rate at 1000 GDD. This was probably the result of soil thaw and translocation of nutrients to support root growth. The timing of this event could have major implications for reindeer productivity because

nutrients are removed from leaves to roots that are more difficult to locate and forage upon.

The R^2 values of the GDD prediction models demonstrate that accumulated heat is a good predictor of chemistry of reindeer forage plants on the Seward Peninsula (Tables 2.1-11). There are differences in annual growth and maturity due to uneven warming of microsites (Bliss, 1956) and year-to-year variation in weather (Van Soest, 1994). Warmer spring temperatures could initiate early leaf emergence and growth thus, setting off an early burst of available nutrients to foraging reindeer (Tieszen, 1978; Deinum, 1984). Higher midsummer temperatures will promote leaf maturity, the formation of fiber, and increase movement of nutrients out of foliar tissue (Hay and Heide, 1984; Hill *et al.*, 1995). Higher midsummer temperatures will also have an effect on cell wall digestibility by accelerating lignification (Deinum 1984; Bennet and Mathias 1984). Thus, summer temperature patterns measured as GDD is a good predictor of nutrient movement and fiber formation within the plant (Hill *et al.*, 1995), which in turn, has effects on diet quality and animal productivity from year to year. Also, similar species of plants will have different quality attributes due to uneven heat distribution across the landscape. Reindeer producers are very familiar with the thermal nuances of their ranges. They can now estimate the nutritional quality of similar ecological sites across their ranges that may have variable thermal characteristics.

The allocation of assimilates during the growing season depends very much on plant growth form. Assimilates are used in different tissue systems to provide structural support of leaves, conduits for gas and water translocation and storage among different

growth forms. The relative concentrations of carbon in these pools will have implications for reindeer nutrition. Hemicellulose, which is used by plants as both a structural and storage component is fairly well digested and an important source of energy for reindeer (Culberson, 1969; Jacobsen and Skjenneberg 1976; Chapin *et al.*, 1986b). Whereas leaves of willows and forbs provide high concentrations of essential nitrogen and minerals during a short time period, graminoids provide a digestible energy source throughout the growing season and into the fall (Fig. 2.19; Tables 2.1-11). Reindeer producers may want to move animals to areas which contain plants high in hemicellulose during fall to enhance fat deposition.

Arctic plants complete growth during a very small window of favorable environmental conditions. The data presented here illustrate the dramatic variability in concentrations of nutrients and fibers across ecological sites and throughout the growing season (Figs, 2.20, 2.21). The producer may see new opportunities to place reindeer in areas where concentrations of nutrients and digestibility of forage plants are high by condensing landscape nutrient dynamics into customized nutritional maps. Placing reindeer in better grazing areas and increasing growth of individual animals will increase overall production of the grazing system. Based on the nutrient maps of the Seward Peninsula, N is dramatically higher in riparian areas and river deltas where there is an abundance of shrubs (Appendix B). However, based on satellite telemetry data and reindeer herder reports (Unpublished data UAF-RRP; http://reindeer.salrm.uaf.edu/) reindeer generally avoid these grazing areas during summer even though there is a high proportion of high N and nutrient forage plants. It is commonly reported among reindeer

producers on the Seward Peninsula that herding reindeer into and through willow thickets is extremely difficult. Free–ranging reindeer on the Seward Peninsula become agitated and balk at edges of shrub communities when herded, presumably because of fear of predation (T. Gray, C. Davis, M. Henry, pers. comm.). The grizzly bear population of the Seward Peninsula has risen since the 1970s (Georgette, 2001) and recently wolves have moved into the area and are preying upon reindeer (Oleson, 2005). A high proportion of summer and fall mortalities of satellite collared reindeer on the Seward Peninsula are found in shrub communities (Oleson, 2005; unpublished data UAF-RRP; http://reindeer.salrm.uaf.edu/). Shrubby areas provide excellent stalking and ambush opportunities for predators and also block the wind which will increase insect abundance and activity.

Reindeer under management in Russia are more productive than unmanaged wild reindeer populations (Andreev, 1975) and producers there may use their grazing resources more efficiently than producers in Alaska. In Chukotka, herders intensively manage their reindeer and have established a close human-animal interaction. Chukotkan herders move reindeer up and down stream and river corridors in the N and nutrient–rich riparian habitats. Under the stewardship of humans, reindeer will feel more secure and actively graze in areas with limited visibility to spot predators. Chukotkan herders also stop and build smudge fires on gravel bars when insect abundance is high. Reindeer will bed down and ruminate under the protective cover of a smudge fire and not move to higher windswept ridges. By using the nutrient mapping system the Seward Peninsula reindeer producers can now visualize the potential gain in production and could adopt a

grazing strategy like the Chukotkan herders to better utilize nutrient rich riparian areas. Lichen reserves on upland slopes would also be conserved by restricting reindeer grazing to lower elevations in summer.

Reindeer in Chukotka have been herded in this manner for hundreds of years. This environment would have allowed domestic reindeer to graze for extended periods on nutrient-rich areas that would have been less available to wild reindeer. Domestic reindeer may as a result have adapted to grazing in more nutrient-rich areas by developing traits such as early primiparity, earlier breeding and calving dates, and higher deposition of lean tissue and fat (Prichard *et al.*, 1999; Finstad and Prichard, 2000; Dmitriez and Ernst, 1989), characteristics distinguishing domestic reindeer and caribou in North America (Finstad *et al.*, 2008).

In conclusion, models of nutrient and fiber dynamics were developed for reindeer forage plants on the Seward Peninsula. These prediction equations were integrated with the NRCS species composition and biomass estimates of ecological sites, ranked and mapped. The producer can access the mapping program over the internet and input a choice of parameters (JD, GDD, PH) for a designated location and resolution (Appendix B) to fit the needs of his decision making. By visualizing the effect of thermal dynamics on forage quality, he can make refinements to his grazing plan and make real time animal placement decisions based on the influence of temperature on forage quality across the environment. The reindeer producer can now monitor a forage quality indicator (phenological stage), that he can use to ensure that his animals are in areas with the highest nutrition available on his range.

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Figures

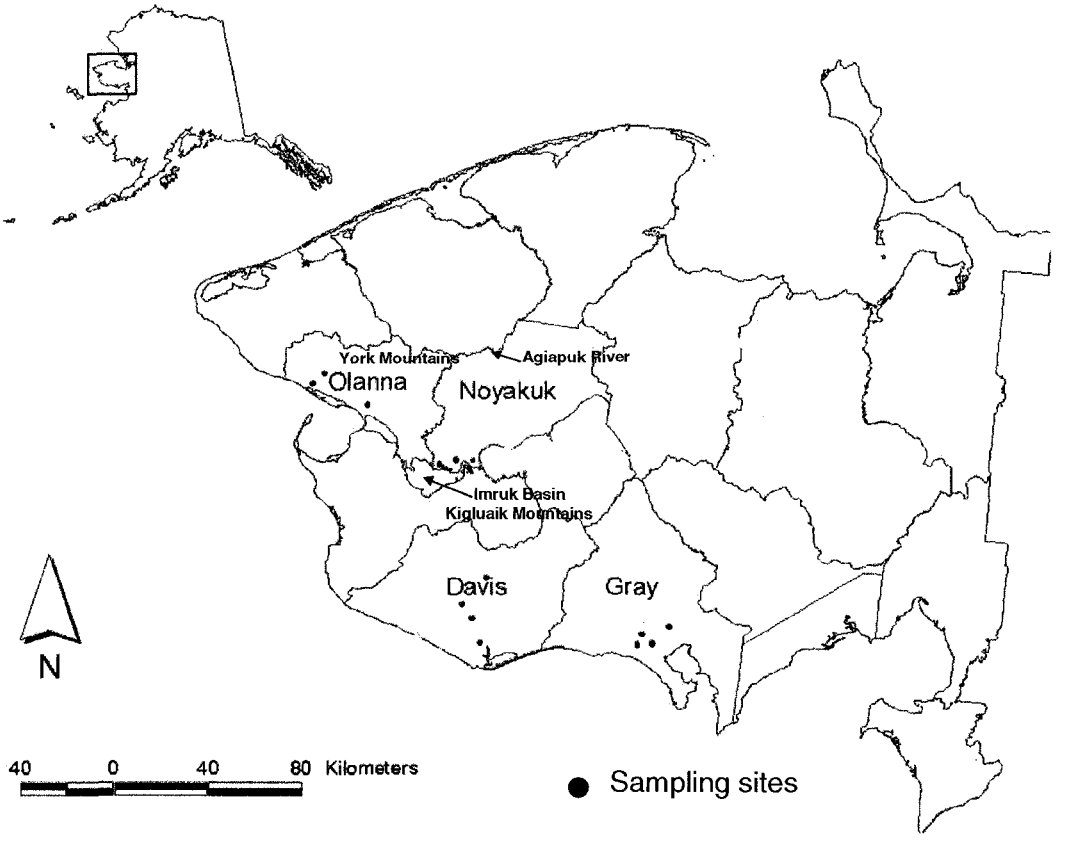

Figure 2.1 Map of fourteen replicate sampling sites on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

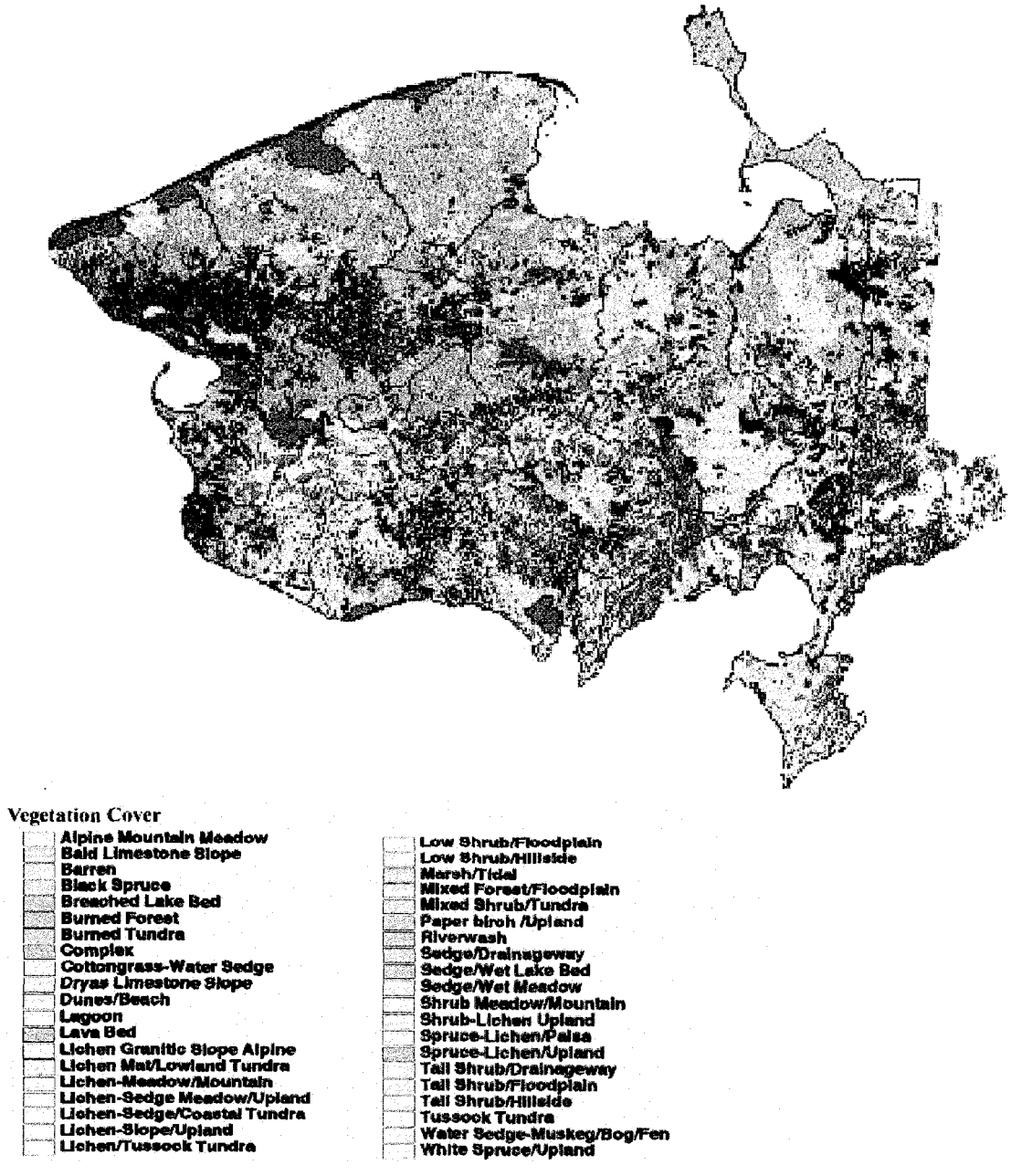

Figure 2.2 Map of the thirty-nine ecological sites identified and mapped by the Natural Resources Conservation Service of the reindeer ranges of the Seward Peninsula, Alaska.

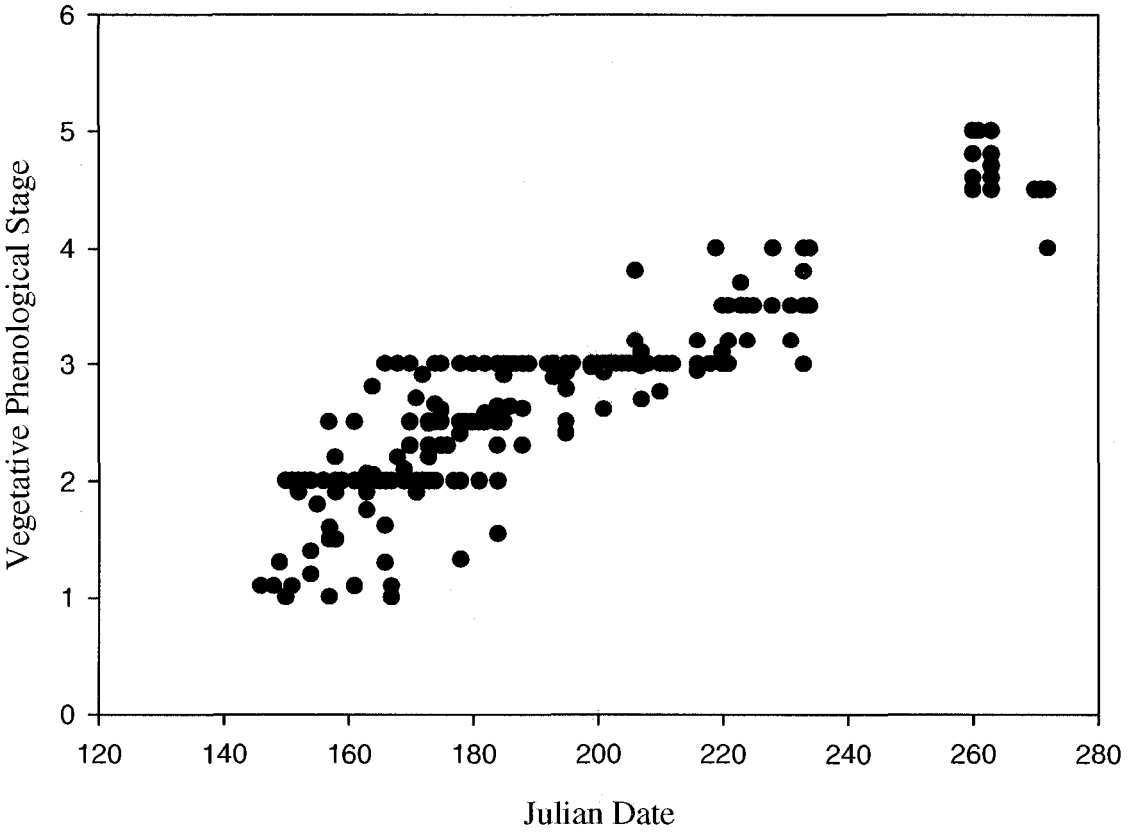

Figure 2.3 Relationship between Julian date and vegetative phenology (see Table 2.1) of leaves of willow; *Salix pulchra,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

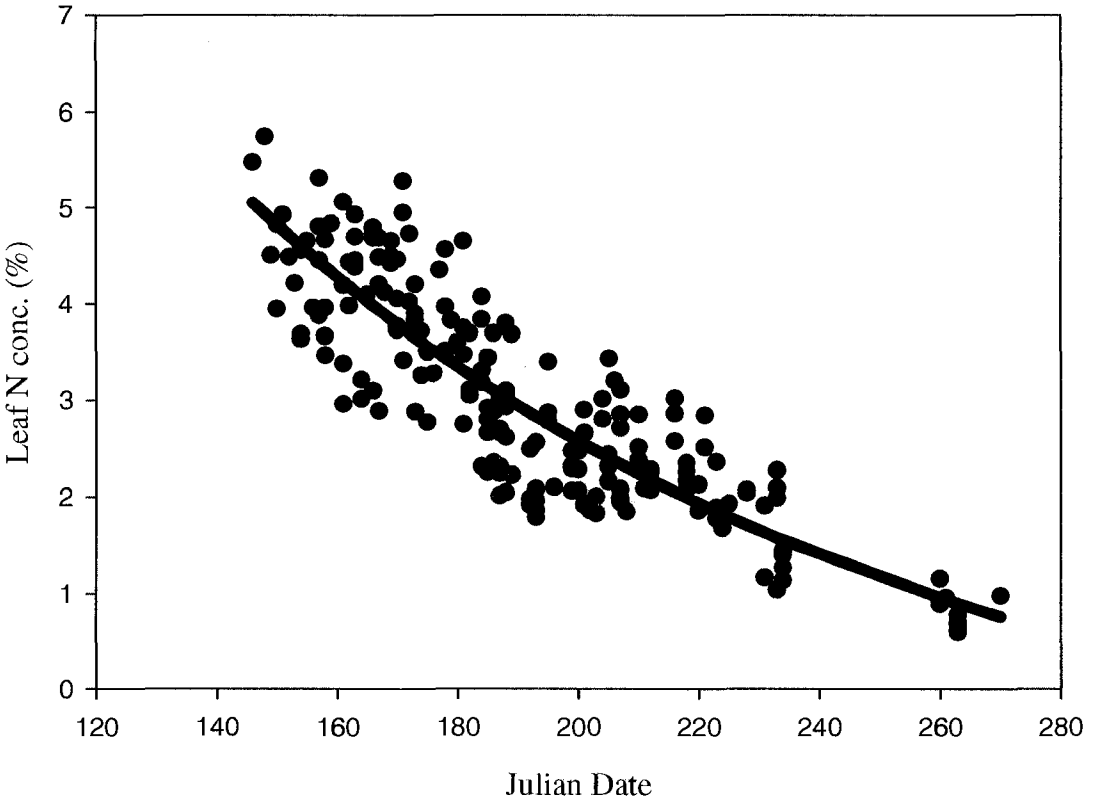

Figure 2.4 Relationship between Julian date (JD) and nitrogen concentration (%) in leaves of willow; *Salix pulchra,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = 16.2-0.1(JD) + 1.6E-4(JD^2). N = 217; R^2 = 0.79; $p < 0.001$.

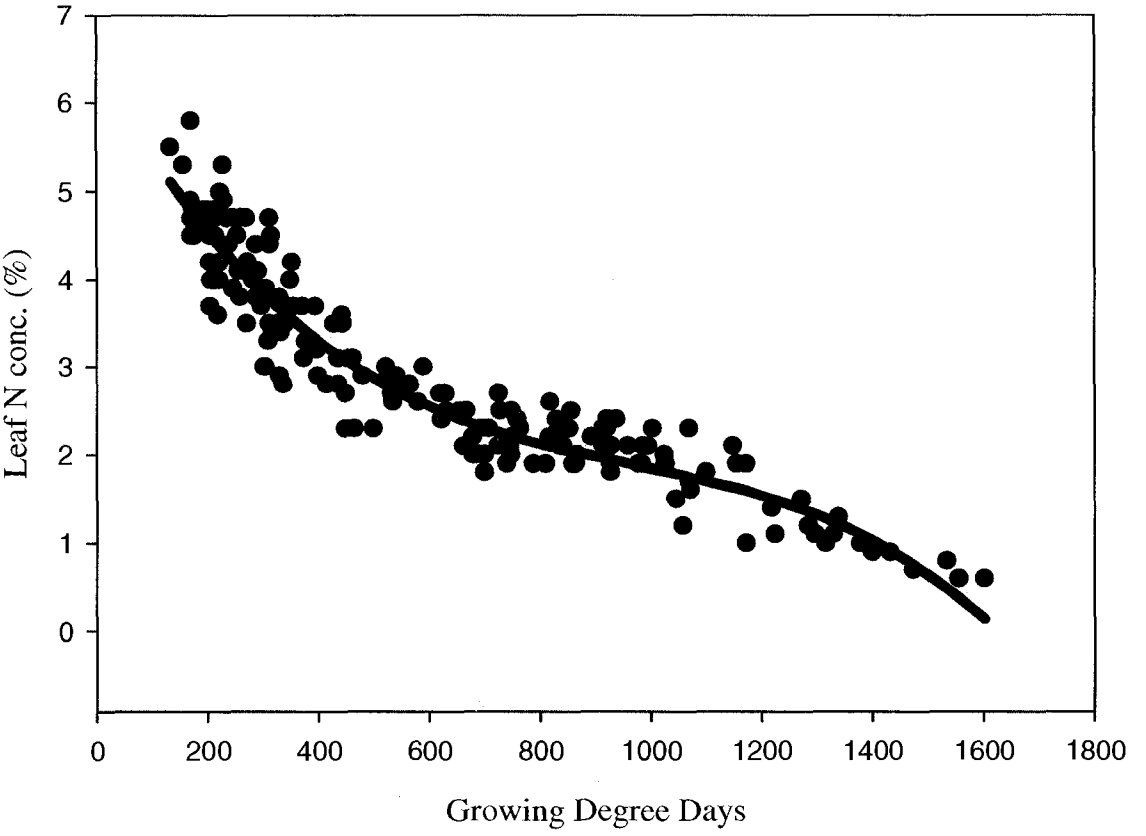

Figure 2.5 Relationship between growing degree days (GDD) and nitrogen concentration (%) in leaves of willow; *Salix pulchra,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = 6.4-1.1E-2(GDD)+1.0E-5(GDD^2)-3.5E-9(GDD^3). N = 209; R^2 = 0.91; $p < 0.001$.

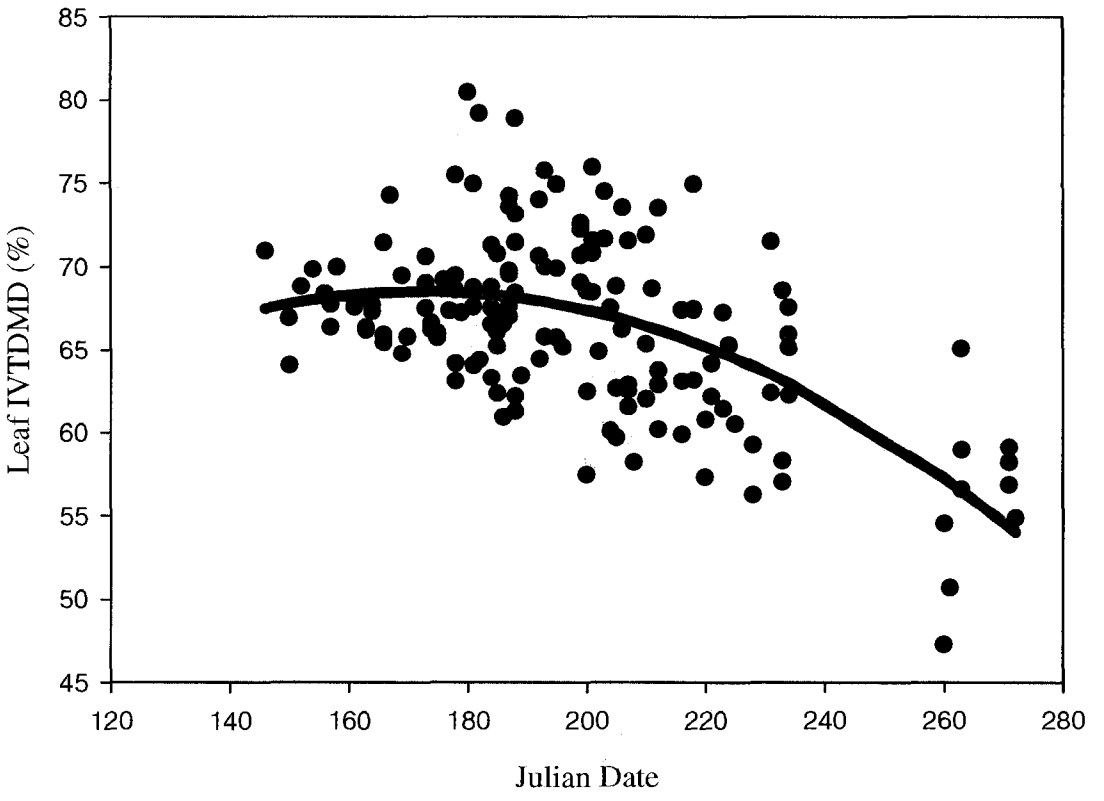

Figure 2.6 Relationship between Julian date (JD) and in vitro true dry matter digestibility (IVTDMD) in leaves of willow; *Salix pulchra,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 25.1+0.5(JD)-1.5E-3(JD^2). N = 162; R^2 = 0.37; $p < 0.001$.

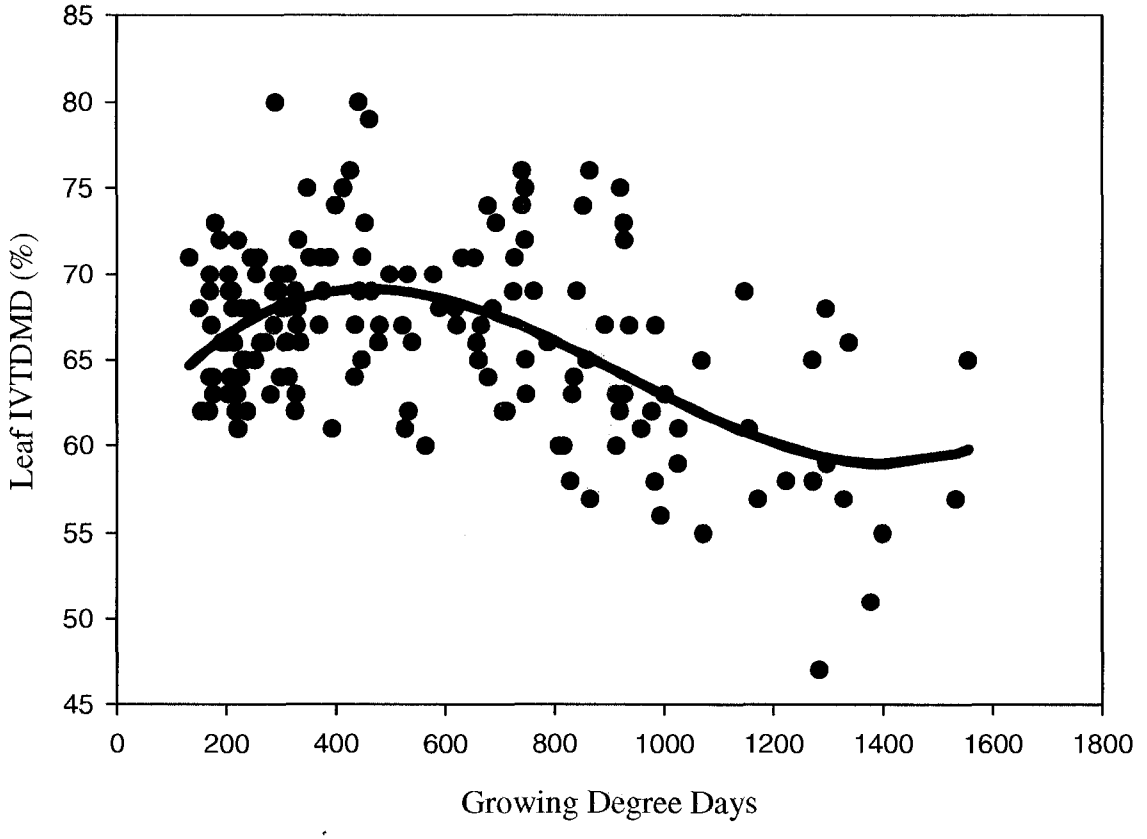

Figure 2.7 Relationship between growing degree days (GDD) and in-vitro true dry matter digestibility (IVTDMD) in leaves of willow; *Salix pulchra* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 6.13+.03(GDD)-4.7E-5(GDD^2)+1.6E-8(GDD^3). N = 174; R^2 = 0.22; $p < 0.001$.

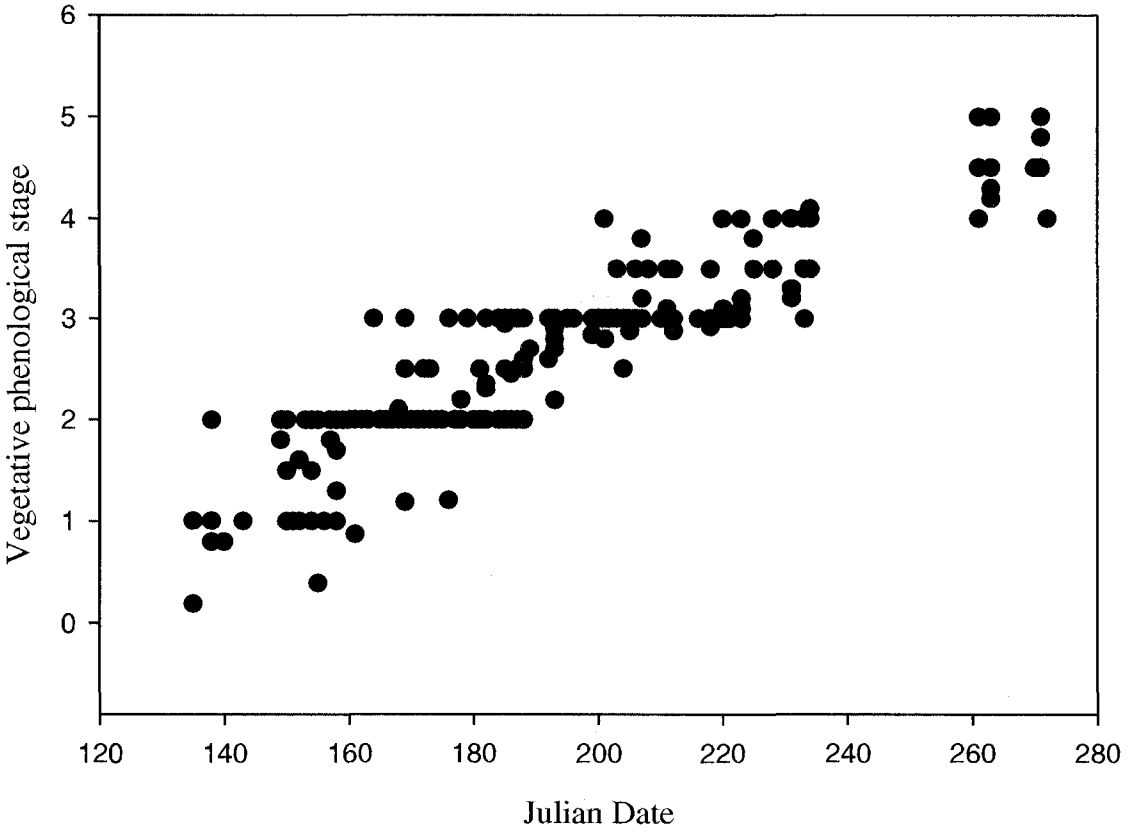

Figure 2.8 Relationship between Julian date and vegetative phenology (see Table 2.1) of leaves of sedge; *Carex aquatilis* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

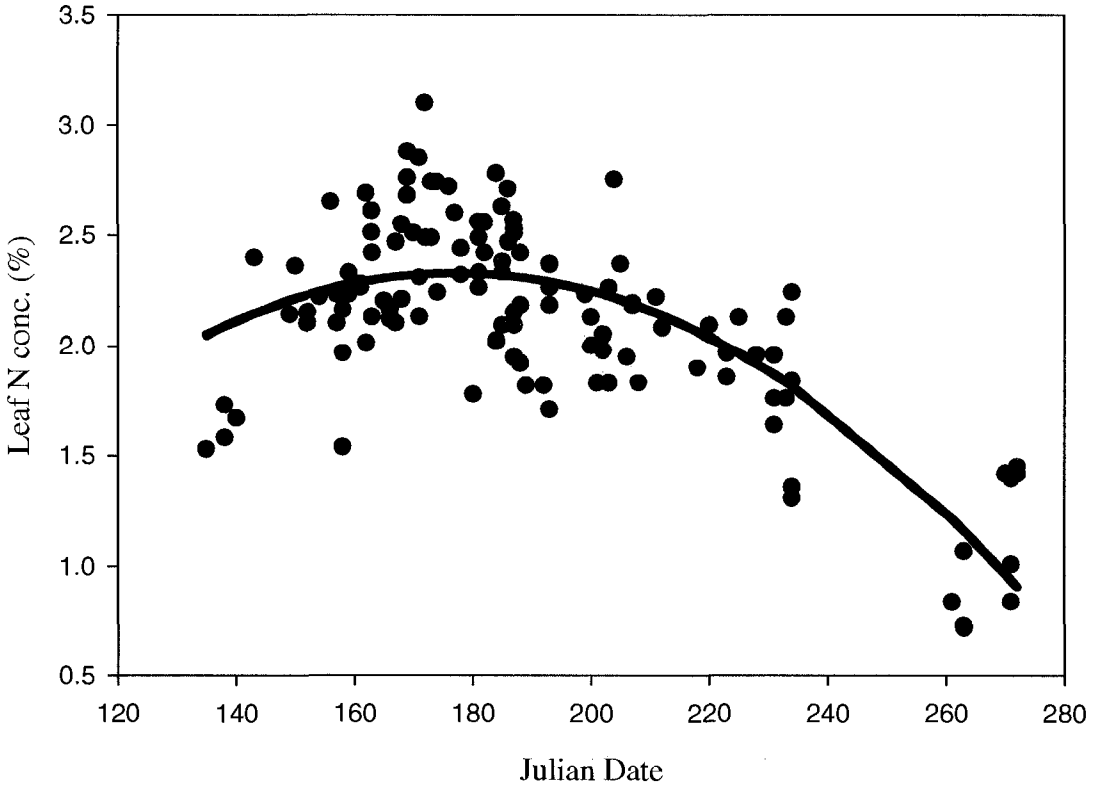

Figure 2.9 Relationship between Julian date (JD) and nitrogen concentration (%) in leaves of sedge; *Carex aquatilis* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = -2.6+0.06(JD)-1.6E-4(JD^2). N = 126, R^2 = 0.59; $p < 0.001$.

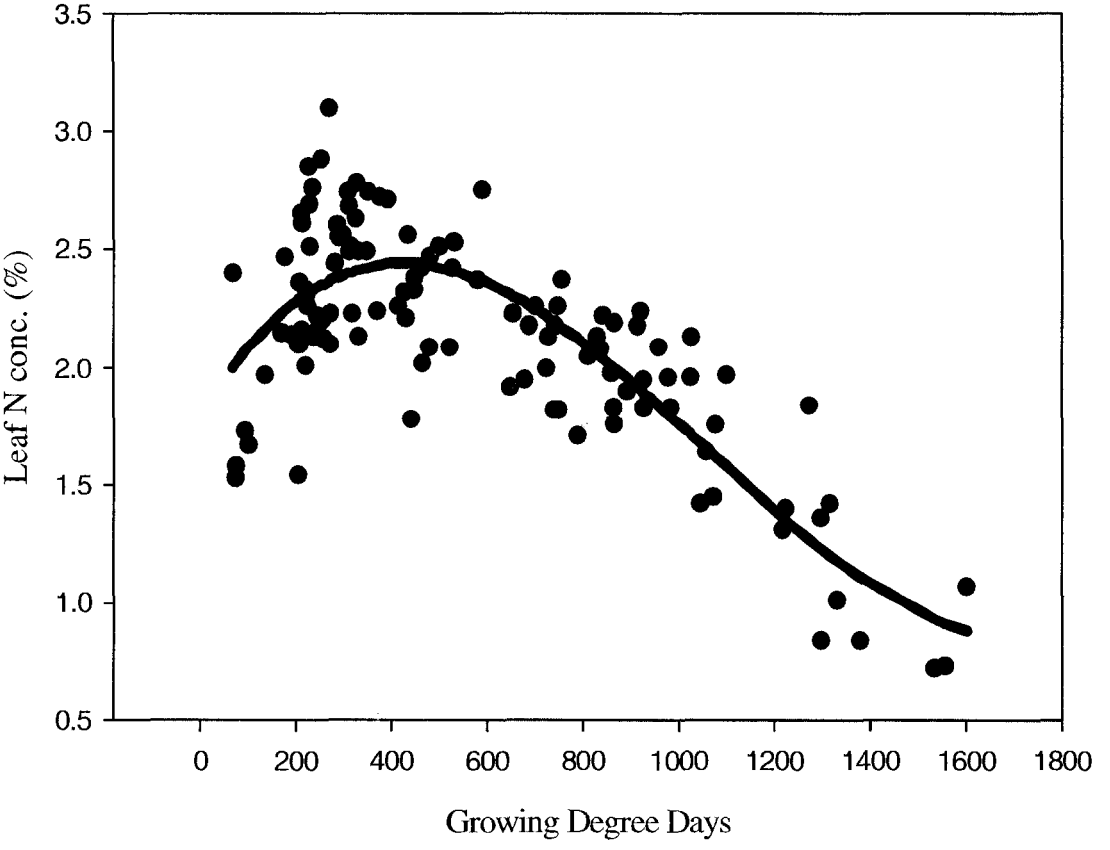

Figure 2.10 Relationship between growing degree days (GDD) and nitrogen concentration (%) in leaves of sedge; *Carex aquatili,s* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = 2.2+8.9E-4(GDD)-1.0E-6(GDD^2). N = 123; R^2 = 0.64; $p < 0.001$.

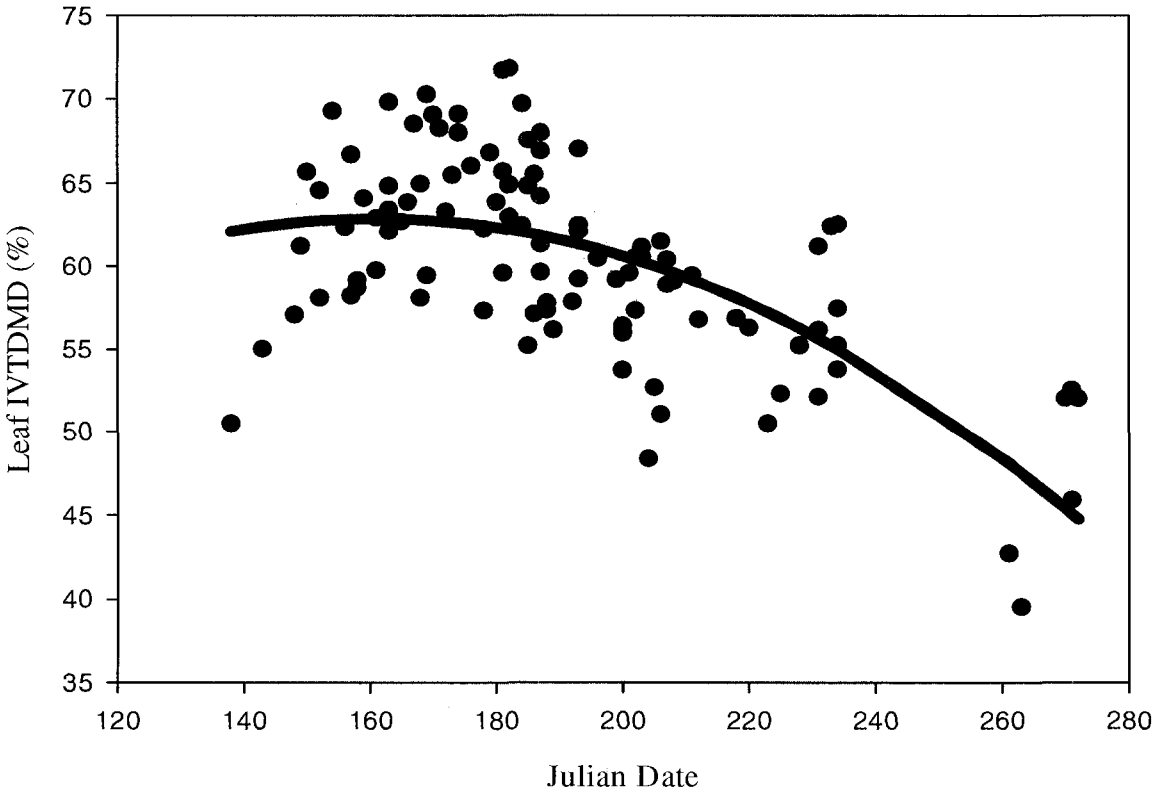

Figure 2.11 Relationship between Julian date (JD) and in vitro true dry matter digestibility (IVTDMD) in leaves of sedge; *Carex aquatilis,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 24.9+0.48(JD)-1.5E-3(JD^2). N = 105; R^2 = 0.46; $p < 0.001$.

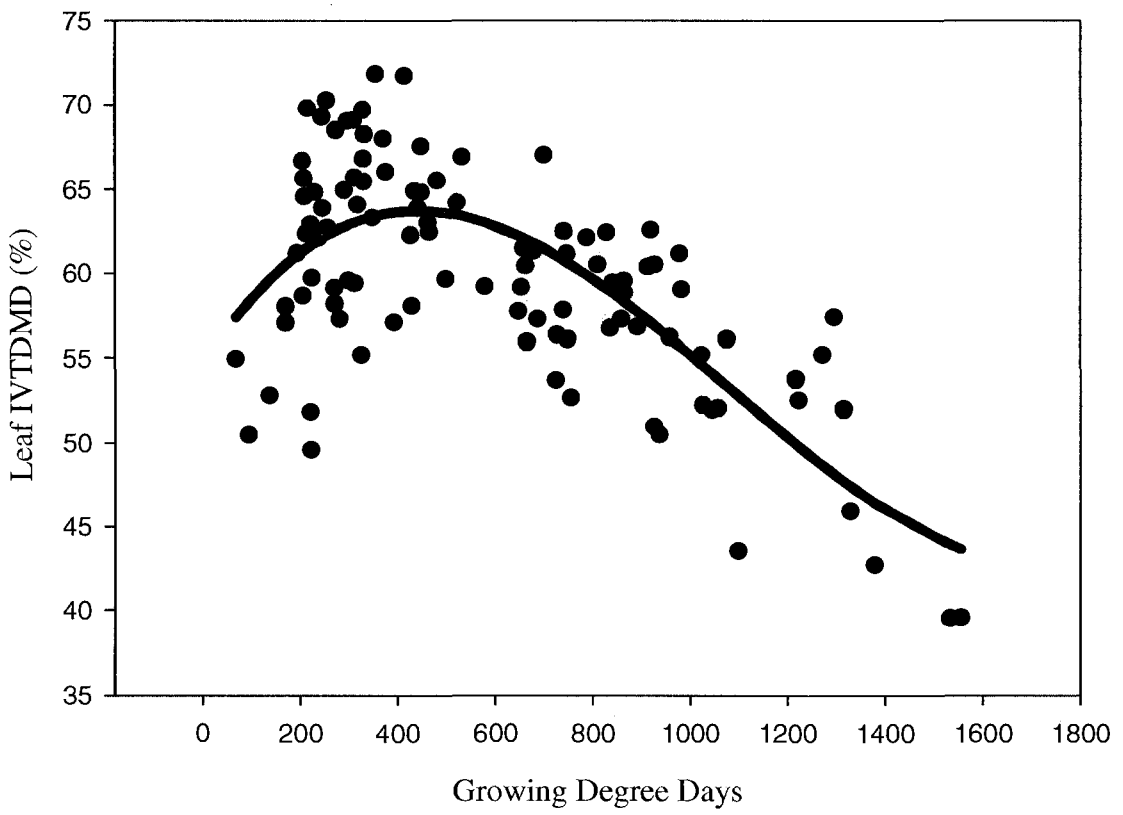

Figure 2.12 Relationship between growing degree days (GDD) and in vitro true dry matter digestibility (IVTDMD) in leaves of sedge; *Carex aquatilis,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 5.5+.045(GDD)-6.4E-5(GDD^2)+0.2E-8(GDD^3). N = 106; R^2 = 0.49; $p < 0.001$.

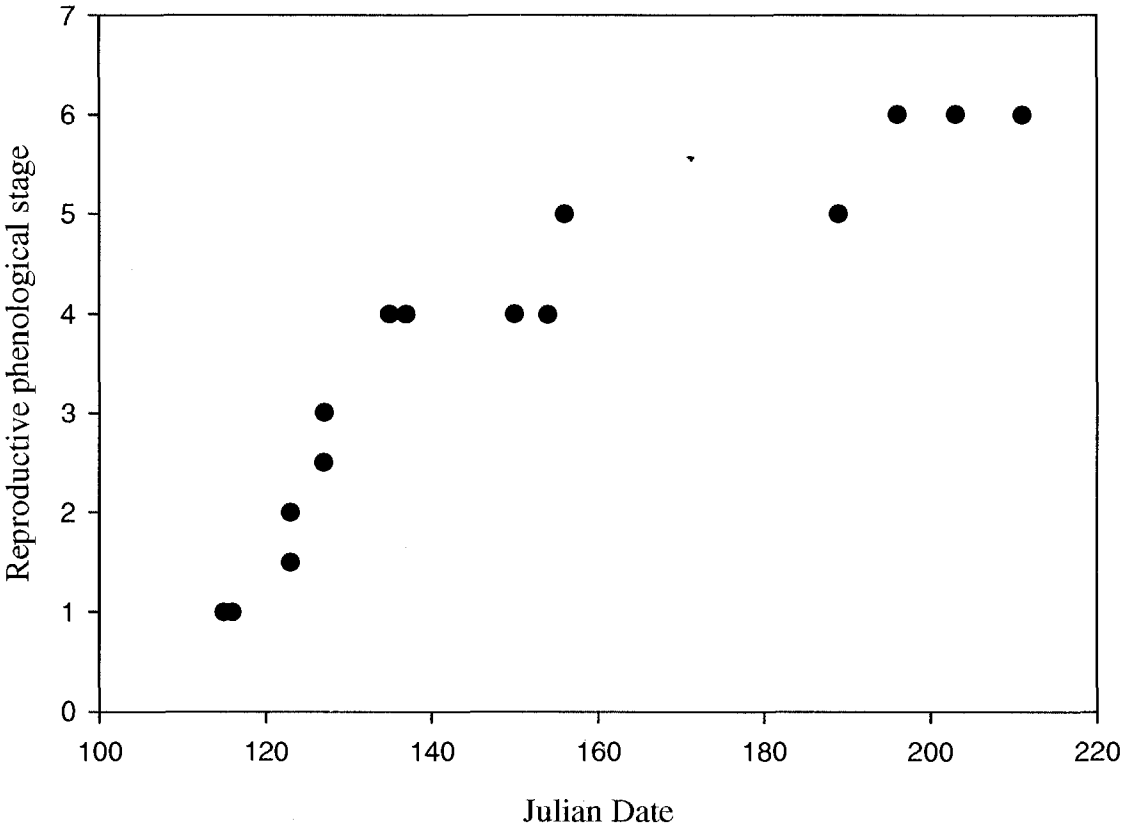

Figure 2.13 Relationship between Julian date and reproductive phenology (see Table 2.1) of inflorescences of *Eriophorum vaginatum,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

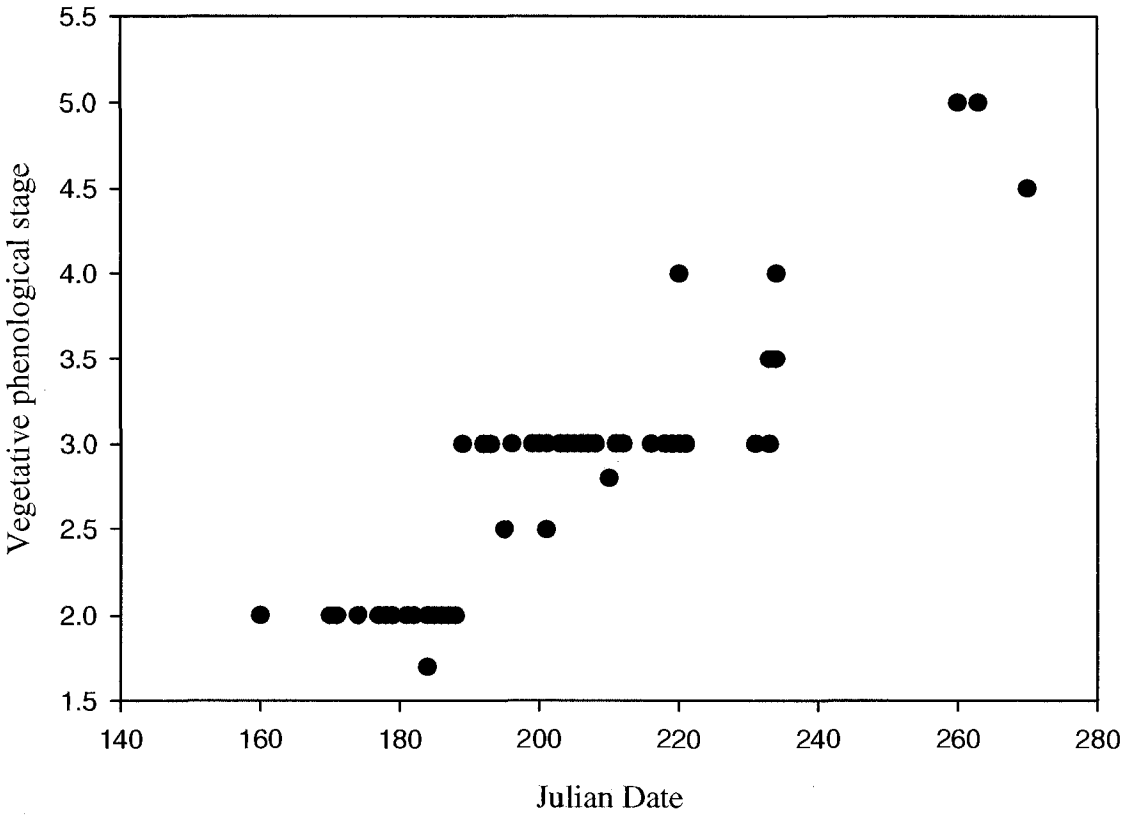

Figure 2.14 Relationship between Julian date (JD) and vegetative phenology (see Table 2.1) of leaves of forb; *Equisetum arvense,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

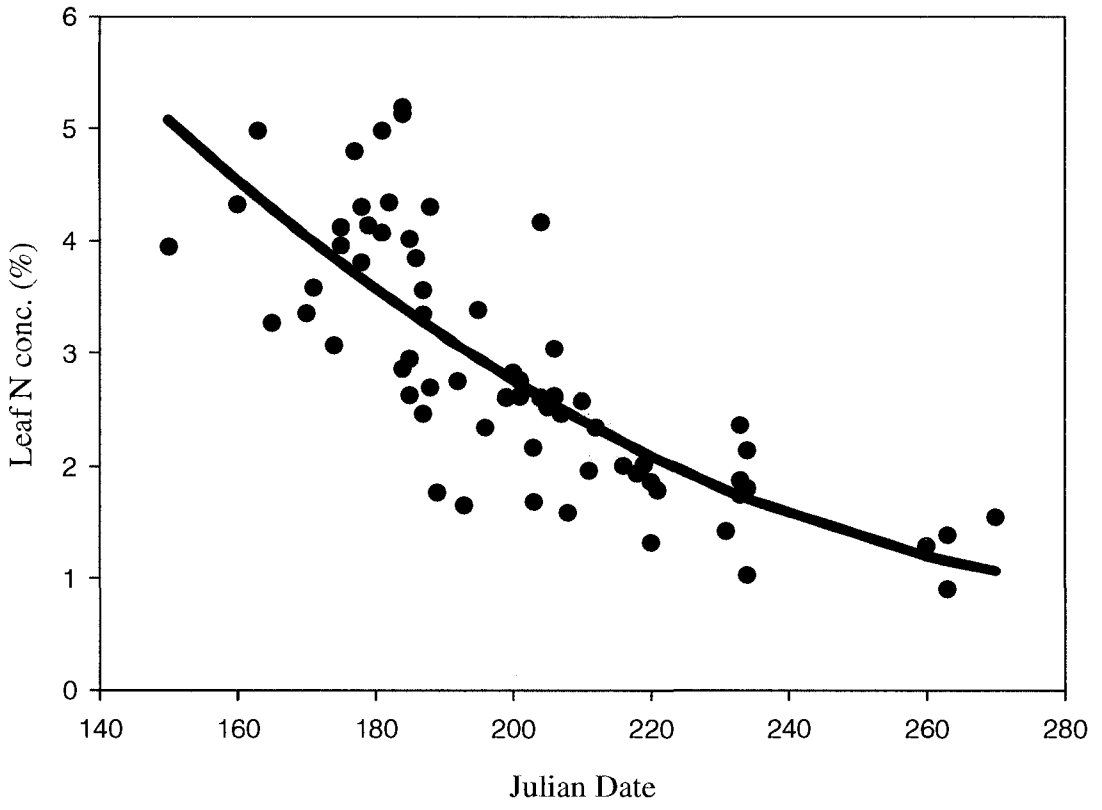

Figure 2.15 Relationship between Julian date (JD) and nitrogen concentration (%) in leaves of forb; *Equisetum arvense,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = 17.5-0.1(JD)+1.8E-4(JD^2). N = 66; $R^2 = 0.70$; $p < 0.001$.

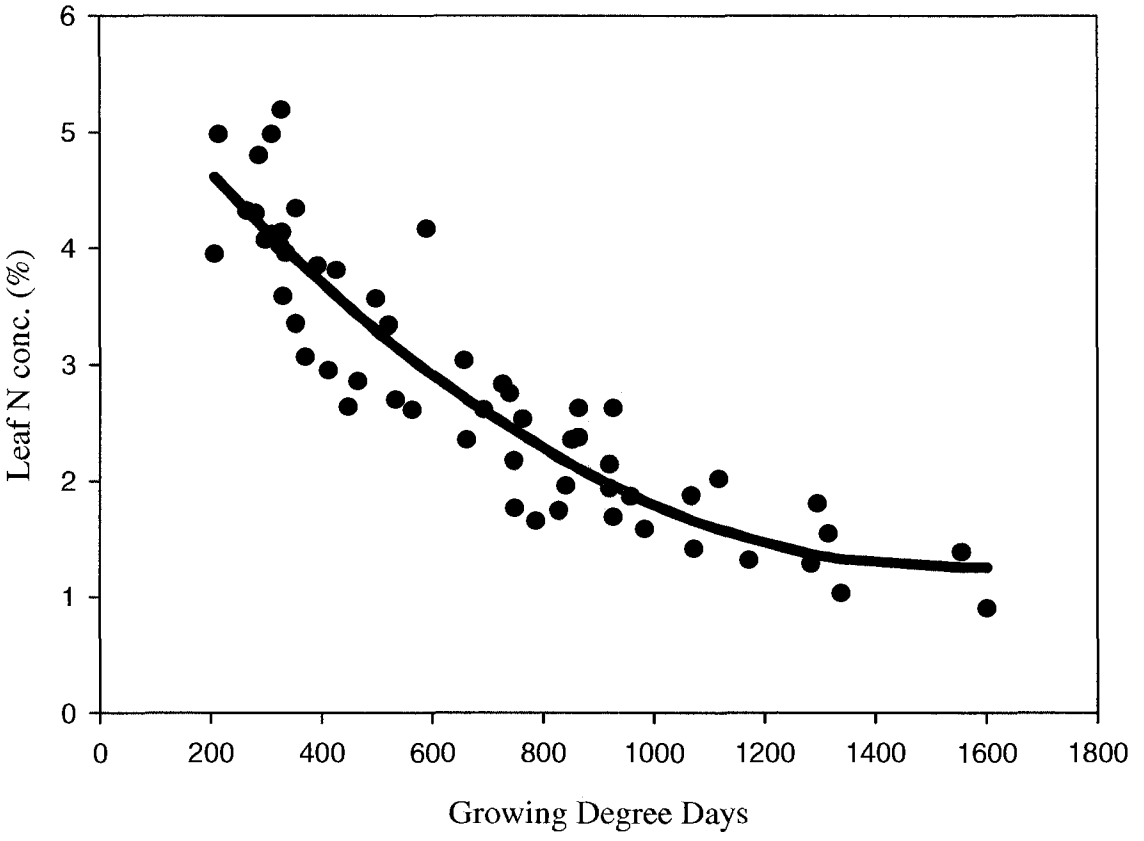

Figure 2.16 Relationship between growing degree days (GDD) and nitrogen concentration (%) in leaves of forb; *Equisetum arvense,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. N(%) = 5.7-5.8E-3(GDD)+1.9E-6(GDD^2). N = 56; $R^2 = 0.84$; $p < 0.001$.

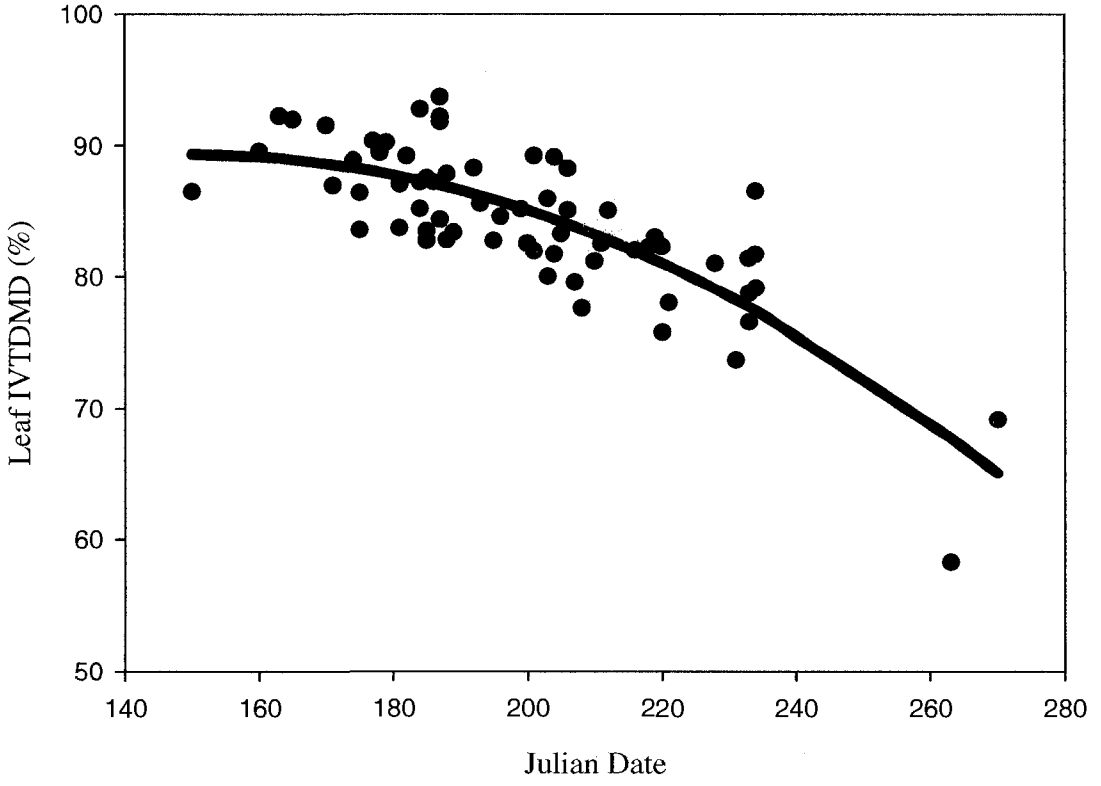

Figure 2.17 Relationship between Julian date (JD) and in-vitro true dry matter digestibility (IVTDMD) of leaves of forb; *Equisetum arvense,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 51.9+0.5(JD)-1.7E-3(JD^2). N = 65; $R^2 = 0.65$; $p < 0.001$.

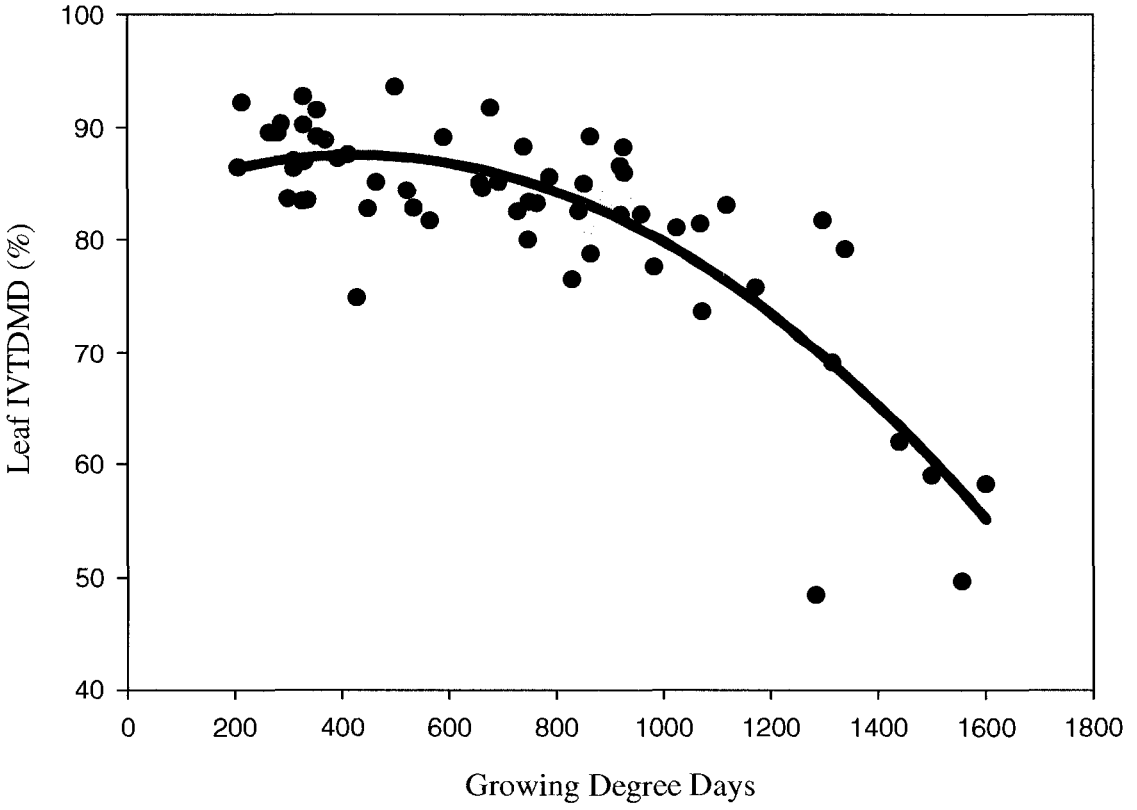

Figure 2.18 Relationship between growing degree days (GDD) and in-vitro true dry matter digestibility (IVTDMD) of leaves of forb; *Equisetum arvense,* found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska. IVTDMD(%) = 83.67+1.8E-2(GDD)-2.1E-5(GDD^2). N = 57; R^2 = 0.66; $p < 0.001$.

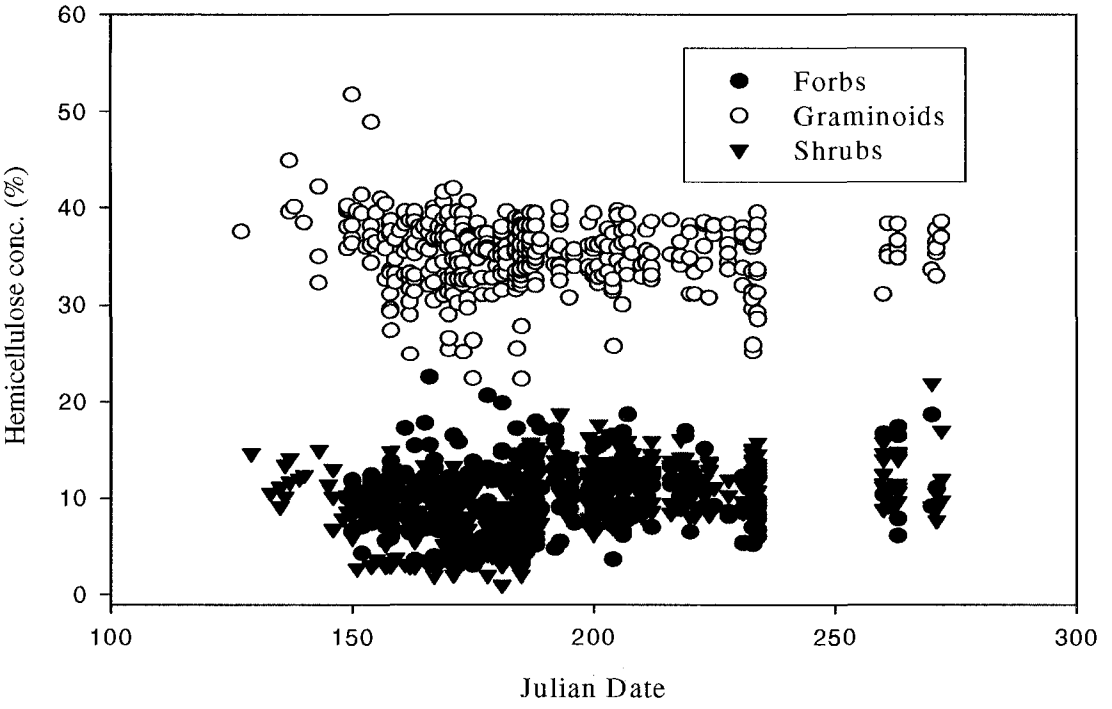

Figure 2.19 Concentration of hemicellulose (%) according to plant growth form; shrub, graminoid or forb, found on the Davis, Gray, Olanna, and Noyakuk reindeer ranges of the Seward Peninsula, Alaska.

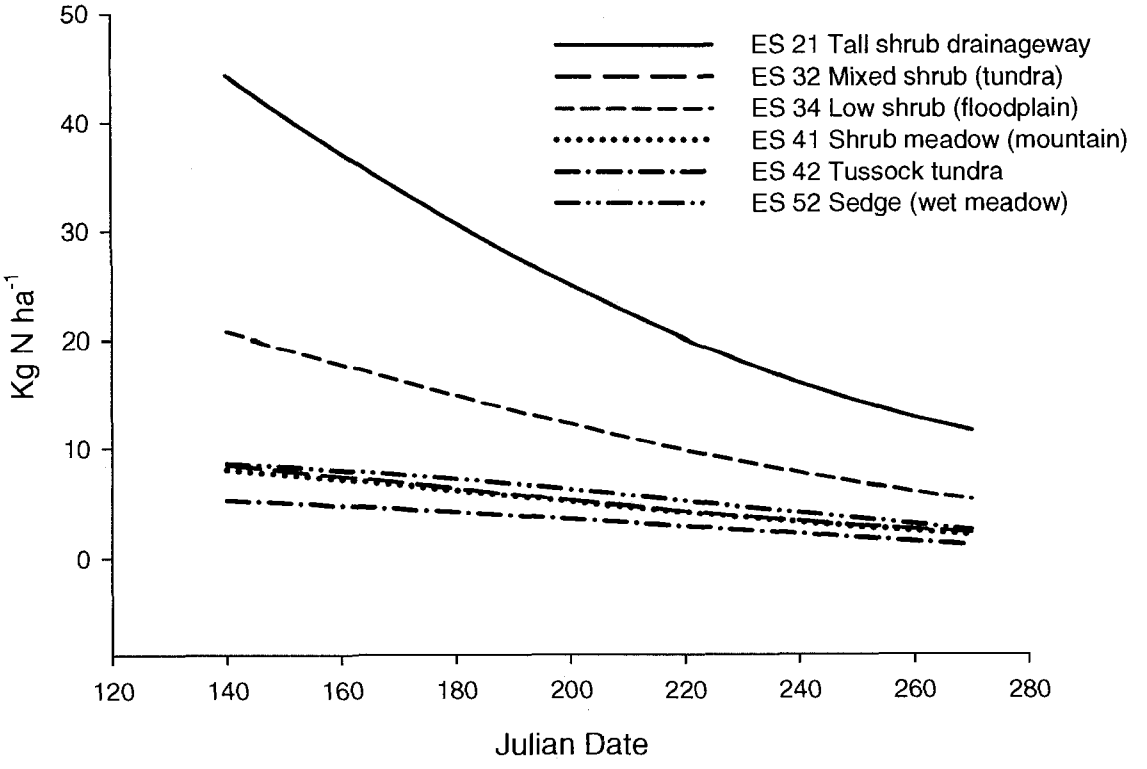

Figure 2.20 Cumulative nitrogen pool of all reindeer forage plants found in select ecological sites (ES) through the growing season on the Seward Peninsula, Alaska.

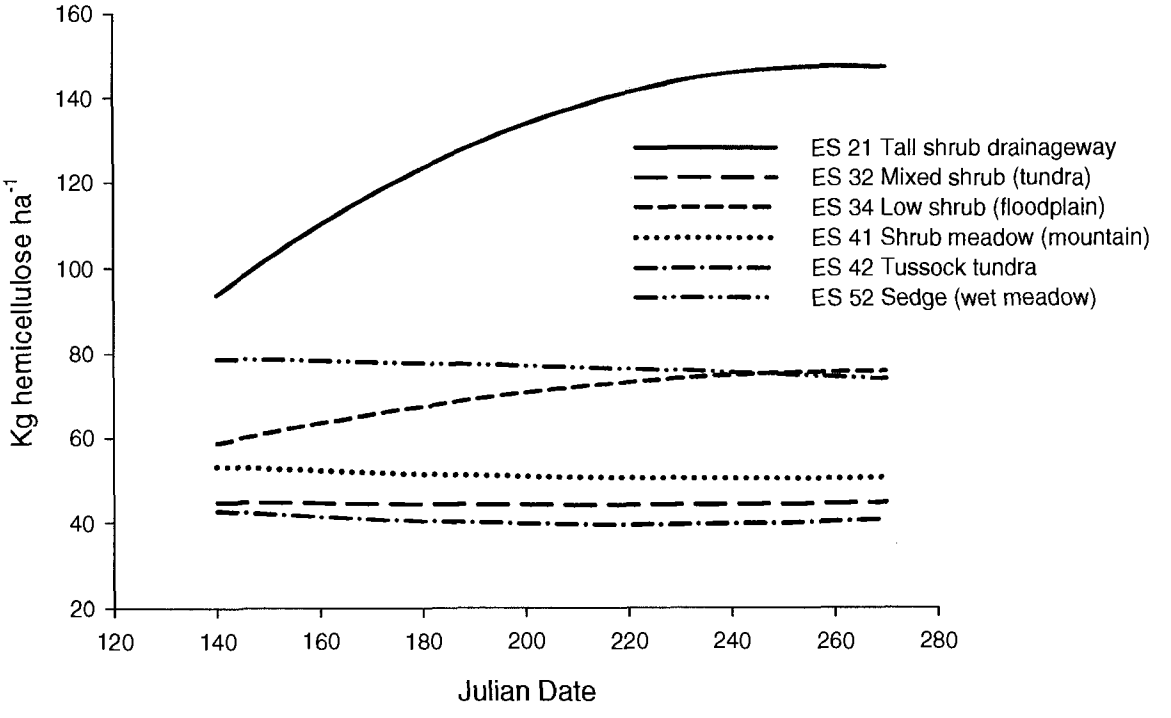

Figure 2.21 Cumulative hemicellulose pool of reindeer forage plants found in select ecological sites (ES) through the growing season on the Seward Peninsula, Alaska.

Tables

Table 2.1 Vegetative and reproductive stages of maturity (phenology) of reindeer forage plants of the Seward Peninsula, Alaska.

Vegetative stage	Description
0	Dormant, no new (current year growth), leaf buds closed
1	Current year culms, stems or leaves elongating and greening (to1/3 of full length) in sedges and grasses, leaf buds opening in shrubs
1.5	Shrubs only, rolled leaf stage
2	Leaves, culms or stems continuing to open in sedges and grasses (to 2/3 of full length), leaves opening in shrubs
2.5	Shrubs only, leaves expanding to 2/3 full length
3	Full leaf / stem expansion
4	Leaves, shoots deteriorating, yellowing
5	Plant senesced
Reproductive stage	Description
0	Dormant, no new floral heads
1	Floral buds emerging
2	Flowers opening
3	Full flower / anthesis
4	Post flower, fruit or pod developing (females), pollen has been shed (males)
5	Mature fruit / seed set (females), flowers deteriorating, senescing (males)
6	Fruits, seeds dispersed (females), flower senesced (males)

Table 2.2 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of nitrogen (N), phosphorus (P) and potassium (K) in willows commonly found in diets of Seward Peninsula reindeer. *Salix pulchra* (SAPU), *Salix lanata* (SALA) , *Salix alexensis* (SAAL), and *Salix fusescence* (SAFU).

Species	N(%)	P(%)	K(%)
SAPU			
JD	16.2-0.1(JD) + 1.6E-4(JD^2)	3.5-2.6E-2(JD)+5.1E-5(JD^2)	4.1-2.2E-2(JD)+3.0E-5(JD^2)
n/R^2/p	217/ 0.79/ <0.001	173/0.79 / <0.001	173/0.55/ <0.001
GDD	6.4-1.1E-2(GDD)+1.0E-5(GDD^2)-3.5E-9(GDD^3)	.9-1.4E-3(GDD)+1.0E-6(GDD^2)	1.7-1.1E-3(GDD)+1.7E-7(GDD^2)
n/R^2/p	209/ 0.91/ <0.001	165/0.75/ <0.001	166/ 0.66/ <0.001
PH	5.3+4.3E-2(PH)-4.2E-2(PH^2)	1.2-1.1E-1(PH)	1.5+9.2E-2(PH)-1.7E-2(PH^2)
n/R^2/p	222/ 0.94/ <0.001	165/ 0.79/ <0.001	165/ 0.70/ < 0.001
SALA			
JD	14.7-8.9E-2(JD)+1.5E-4(JD^2)	3.1-2.4E-2(JD)+4.7E-5(JD^2)	3.1-9.8E-3(JD)
n/R^2/p	64/ .75/ <.001	30/ .79/ <.001	30/ .69/ <.001
GDD	7.2-1.7E-2(GDD)+1.9E-5(GDD^2)-7.5E-9(GDD^3)	.77-1.2E-3(GDD)+1E-6(GDD^2)	1.8-9.6E-4(GDD)
n/R^2/p	55/ .91/ <.001	29/ .92/ <.001	29/ .84/ <.001
PH	-4.1+3.9(PH)-5.3E-1(PH^2)+2.1E-2(PH^3)	1.1-.1(PH)	2.8-.2(PH)
n/R^2/p	64/ 0.76/ < 0.001	29/ 0.86/ < 0.001	29/ 0.70/ < 0.001
SAAL			
JD	16.4-.1(JD)+1.8E-4(JD^2)	3.9-3.1E-2(JD)+6.3E-5(JD^2)	6.1-3.9E-2(JD)+7.4E-5(JD^2)
n/R^2/p	63/ .70/ <.001	47/ .78/ <.001	47/ .69/ <.001
GDD	6.8-1.3E-2(GDD)+1.3E-5(GDD^2)-4.3E-9(GDD^3)	1.1-2.6E-3(GDD)+2E-6(GDD^2)-7.4E-10(GDD^3)	2.1 -1.8E-3(GDD)+1.0E-6(GDD^2)
n/R^2/p	52/ .87/ <.001	46/ .92/ <.001	46/ .80/ <.001
PH	5.5+6.8E-2(PH)-4.4E-2(PH^2)	1.1-9.4E-2(PH)-5.8E-4(PH^2)	1.8+8.9E-2(PH)-1.7E-2(PH^2)
n/R^2/p	61/ 0.83/ < 0.001	45/ 0.87/ < 0.001	45/ 0.76/ < 0.001
SAFU			
JD	23.99-0.18(JD)+3.6E-4(JD^2)	24.54-0.33(JD)+1.5E-3(JD^2)-2E-6(JD^3)	2.74-9E-3(JD)
n/R^2/p	29/ 0.81/ < 0.001	29/ 0.90/ < 0.001	29/ 0.90/ < 0.001
GDD	7-1.5E-2(GDD)+1.5E-5(GDD^2)-5.05E-9(GDD^3)	.96-2.3E-3(GDD)+2E-5(GDD^2)-7.2E-10(GDD^3)	1.5-6.8E-4(GDD)
n/R^2/p	29/ 0.94/ < 0.001	29/ .0.90/ < 0.001	29/ 0.92/ < 0.001
PH	5.98-0.4(PH)-7.5E-3(PH^2)	0.76-6.2E-2(PH)	0.6+0.17(PH)-1.7E-3(PH^2)

$n/R^2/p$	29/ 0.88/ < 0.001	29/ 0.86 < 0.001	29/ 0.88/ < 0.001

Table 2.3 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) in willows commonly found in diets of Seward Peninsula reindeer. *Salix pulchra* (SAPU), *Salix lanata* (SALA), *Salix alexensis* (SAAL), and *Salix fusescence* (SAFU).

Species	NDF(%)	ADF(%)	IVTDMD(%)
SAPU			
JD	-29.2+0.39(JD)-6.4E-4(JD^2)	15.4-8.1E-2(JD)+3.5E-4(JD^2)	25.1+0.5(JD)-1.5E-3(JD^2)
$n/R^2/p$	226/ 0.45/ < 0.001	226/ 0.49/ < 0.001	162/ 0.37/ <0.001
GDD	12.04+2.3E-2(GDD)-7.0E-6(GDD^2)	9.96+3.7E-3(GDD)+2.0E-6(GDD^2)	6.13+0.03(GDD)-4.7E-5(GDD^2)+1.6E-8(GDD^3)
$n/R^2/p$	211/ 0.59/< 0.001	210/ 0.63/ < 0.001	177/ 0.22/ < 0.001
PH	12.3-0.18(PH)+0.18(PH^2)	13.54-1.59(PH)+0.18(PH^2)	47.73+6.72(PH)-0.52(PH^2)
$n/R^2/p$	224/ 0.61/ < 0.001	223/ 0.61/ < 0.001	188/ 0.21/ < 0.001
SALA			
JD	4.0+0.09(JD)	65.79-0.57(JD)+1.5E-3(JD^2)	-31.25+1.1(JD)-2.6E-3(JD^2)
$n/R^2/p$	61/ 0.41/ < 0.001	62/ 0.63/ < 0.001	58/ 0.29/ < 0.001
GDD	17.2+8E-3(GDD)	15.3-1.2E-2(GDD)+1.1E-5(GDD^2)	66.7+0.02(GDD)-1.7E-5(GDD^2)
$n/R^2/p$	53/ 0.50/ < 0.001	53/ 0.64/ < 0.001	58/ 0.27/ < 0.001
PH	68.2-13.76(PH)+0.96(PH^2)	44.82-9.0(PH)+0.61(PH^2)	48.52+8.2(PH)-0.57(PH^2)
$n/R^2/p$	60/ 0.66/ < 0.001	61/ 0.61/ < 0.001	54/ 0.21/ < 0.001
SAAL			
JD	65.98-.49(JD)+1.5E-3(JD^2)	62.33-.48(JD)+1.3E-3(JD^2)	-36.17+1.14(JD)-3.1E-3(JD^2)
$n/R^2/p$	63/0 .70 / < 0.001	62/ 0.58/ < 0.001	60/ 0.68/ < 0.001
GDD	21.04+1.2E-2(GDD)	18.69-0.01(GDD)+9.0E-6(GDD^2)	62.53+0.02(GDD)-2.0E-5(GDD^2)
$n/R^2/p$	50/ 0.60/ < 0.001	52/ 0.51/ < 0.001	50/ 0.58/ < 0.001
PH	54.96-10.33(PH)+0.83(PH^2)	37.57-6.64(PH)+0.48(PH^2)	26.18+12.98(PH)-0.96(PH^2)
$n/R^2/p$	58/ 0.59/ < 0.001	61/ 0.39/ < 0.001	53/ 0.32/ < 0.001
SAFU			
JD	-139.55+1.44(JD)-2.9E-3(JD^2)	30.79+0.36(JD)-5.9E-4(JD^2)	97.65-4.3E-2(JD)-4.4E-4(JD^2)
$n/R^2/p$	24/ 0.81/ < 0.001	24/ 0.75/ < 0.001	24/ 0.76/ < 0.001
GDD	10.0+3.9E-2(GDD)-1.3E-5(GDD^2)	9.8+1.3E-2(GDD)-3E-6(GDD^2)	81.0-9.3E-3(GDD)-4.0E-6(GDD^2)
$n/R^2/p$	24/ 0.90/ < 0.001	24/ 0.76/ < 0.001	24/ 0.71/ < 0.001
PH	10.9+0.61(PH)+0.2(PH^2)	13.5-1.26(PH)+0.2(PH^2)	58.01+8.19(PH)-0.75(PH^2)

$n/R^2/p$	24/ 0.91/ < 0.001	24/ 0.76/ < 0.001	24/ 0.76/ < 0.001

Table 2.4 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of nitrogen (N), phosphorus (P) and potassium (K) in sedges commonly found in diets of Seward Peninsula reindeer. (*Carex aquatilis* (CAAQ), *Carex bigelowii* (CABI), and *Carex lyngbyaei* (CALY).

Species	N(%)	P(%)	K(%)
CAAQ			
JD	-2.6+5.6E-2(JD)+1.8E-4(JD^2)	-2.5+4.2E-2(JD)-2.2E-4(JD^2)+3.4E-7(JD^3)	-17.8+2.9E-1(JD)-1.4E-3(JD^2)+2E-6(JD^3)
$n/R^2/p$	126 / .59 / <.001	116 / .47 / <.001	119 / .57/ <.001
GDD	2.2+8.9E-4(GDD)-1E-6(GDD^2)	.23+1.2E-4(GDD)-4.3E-7(GDD^2)+1.8E-10(GDD^3)	1.1+2.3E-3(GDD)-4E-6(GDD^2)+1.3E-9(GDD^3)
$n/R^2/p$	123 / .64 / <.001	114 / .58 /<.001	117 / .6/<.001
PH	2+2.1E-1(PH)-2.8E-2(PH^2)	.19+5.1E-2(PH)-1.2E-2(PH^2)+5.8E-4(PH^3)	1.2+1.6E-1(PH)-2.2E-2(PH^2)
$n/R^2/p$	126 / 0.60 / <.001	103 / .57 / <.001	105 / .62 / <.001
CABI			
JD	-11.4+2.4E-1(JD)-1E-3(JD^2)+2E-6(JD^3)	1.1-7E-3(JD)+1.1E-5(JD^2)	-1.3+3.7E-2(JD)-1.2E-4(JD^2)
$n/R^2/p$	88 / .78 / <.001	76 / .79 / <.001	76 / .80 / <.001
GDD	3.6-1.9E-3(GDD)	3.8E-1-4.4E-4(GDD)+2E-7(GDD^2)	1.6+3.7E-4(GDD)-9E-7(GDD^2)
$n/R^2/p$	88 / .86 / <.001	73 / .89 / <.001	73 / .76 / <.001
PH	3.2-1.2E-1(PH)-2.9E-2(PH^2)	4.4E-1-3.5E-2(PH)	1.1+2.5E-1(PH)-2.7E-2(PH^2)
$n/R^2/p$	88 / .76 /<.001	60 / .85 / <.001	60 / .61 / <.001
CALY			
JD	-6.9+.11(JD)-2.9E-4(JD^2)	-6.8+.11(JD)-5.6E-4(JD^2)	4.8-1.2E-2(JD)-9E-6(JD^2)
$n/R^2/p$	41/ .44/ <.001	38/ .43/ <.001	38/ .39/ <.001
GD	2.2-3.1E-3(GDD)-3E-6(GDD^2)	.37-7.4E-5(GDD)-1.2E-7(GDD^2)	3-1.4E-3(GDD)-1.1E-7(GDD^2)
$n/R^2/p$	39/ .47/ <.001	36/ .39/ <.001	36/ .42 <.001
PH	2.1+.46(PH)-5.6E-2(PH^2)	.31+2.7E-2(PH)-5E-3(PH^2)	2.5+.11(PH)-2.6E-2(PH^2)
$n/R^2/p$	40/ .51 <.001	32/ .43/ <.001	32/ .42 <.001

Table 2.5 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) in sedges commonly found in diets of Seward Peninsula reindeer. (*Carex aquatilis* (CAAQ), *Carex bigelowii* (CABI), and *Carex lyngbyaei* (CALY).

Species	NDF(%)	ADF(%)	IVTDMD(%)
CAAQ			
JD	106.7-.43(JD)+1E-3(JD^2)	58.1-.32(JD)+8.1E-4(JD^2)	24.9+0.48(JD)-1.5E-3(JD^2)
n/R^2/p	126 / 0.59 / <0.001	122/ 0.35/ <0.001	105/ 0.46/ <0.001
GDD	2.2+8.9E-4(GDD)-1E-6(GDD^2)	28.8-9E-3(GDD)+7E-6(GDD^2)	5.5+.045(GDD)-6.4E-5(GDD^2)+.2E-8(GDD^3)
n/R^2/p	123 / 0.64 / <0.001	119/ .29/ <.001	106/ .49/ <.001
PH	2+2.1E-1(PH)-2.8E-2(PH^2)	28.6-.97(PH)+8.2E-2(PH^2)	56.4+3.4(PH)-.4(PH^2)
n/R^2/p	126 / .60 / <.001	122/ .14/ <.001	100/ .50/ <.001
CABI			
JD	129.4-6.9E-1 (JD)+1.7E-3(JD^2)	1.11.1-7E-3(JD)+1.1E-5(JD^2)	-1.3+3.7E-2(JD)-1.2E-4(JD^2)
n/R^2/p	87 / .41 / <.001	76 / .79 / <.001	76 / .80 / <.001
GDD	65.3-1.9E-2 (GDD)+1.3E-5(GDD^2)	3.8E-1-4.4E-4(GDD)+2E-7(GDD^2)	1.6+3.7E-4(GDD)-9E-7(GDD^2)
n/R^2/p	87 / .44 / <.001	73 / .89 / <.001	73 / .76 / <.001
PH	70-2.9(PH)+1.9E-1(PH^2)	4.4E-1-3.5E-2(PH)	1.1+2.5E-1(PH)-2.7E-2(PH^2)
n/R^2/p	86 / .17 / <.001	60 / .85 / <.001	60 / .61 / <.001
CALY			
JD	142.8-.86(JD)+2.1E-3(JD^2)	75-.53(JD)+1.4E-3(JD^2)	-263.5+3.8(JD)-1E-2(JD^2)
n/R^2/p	41/ .30/ .001	41/ .39 / <.001	39/ .37/ <.001
GDD	66.8-3.3E-2(GDD)+2.6E-5(GDD^2)	29.1-2E-2(GDD)+1.7E-5(GDD^2)	59.4+7.4E-2(GDD)-7.7E-5(GDD^2)
n/R^2/p	39/ .34 /<.001	39/ .47/ <.001	37/ .31/ .002
PH	65-3.4(PH)+.35(PH^2)	28.2-2.1(PH)+.23(PH^2)	56.5+11.4(PH)-1.4(PH^2)
n/R^2/p	40/ .33/ <.001	40/ .40 / <,001	36/ .44/ <.001

Table 2.6 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of nitrogen (N), phosphorus (P) and potassium (K) in leaves of graminoids; *Calamagrostis canadensis* (CACA), *Eriophorum angustifolium* (ERAN) and inflorescences of *Eriophorum vaginatum* (ERVA) found in diets of Seward Peninsula reindeer.

Species	N(%)	P(%)	K(%)
CACA			
JD	23.3-.18(JD)+3.8E-4(JD^2)	-11.3+.18(JD)-9E-4(JD^2)+1E-6(JD^3)	-48.7+.8(JD)-4.1E-3(JD^2)+7E-6(JD^3)
n/R^2/p	20/ .71/ <.001	36/ .51/ <.001	36/ .63/ <.001
GDD	5.2-8.1E-3(GDD)+5E-6(GDD^2)	.25-4.2E-4(GDD)-1E-6(GDD^2)+5.4E-10(GDD^3)	2.6-2.9E-3(GDD)+1E-6(GDD^2)
n/R^2/p	20/ .82/ <.001	36/ .62/ <.001	36/ .69/ <.001
PH	2.8+.24(PH)-4.2E-2(PH^2)	.23+6.5E-2(PH)-8.4E-3(PH^2)	2.0+.05(PH)-2.5E-2(PH^2)
n/R^2/p	20/ .56/ <.001	15/ .57/ .007	15/ .49/ .016
ERAN			
JD	-43.9+.72(JD)-3.6E-3(JD^2)+6E-6(JD^3)	1.36-9.9E-3(JD)+2.1E-5(JD^2)	6.99-4.8E-2(JD)+9.2E-5(JD^2)
n/R^2/p	55/ .35/ <.001	52/ .30/ <.001	52/ .41/ <.001
GDD	2.1+3.7E-3(GDD)-8E-6(GDD^2)+3.7E-9(GDD^3)	.42-4.7E-4(GDD)+2.4E-7(GDD^2)	2.2-2.5E-3(GDD)+1E-6(GDD^2)
n/R^2/p	54/ .43/ <.001	51/ .53/ <.001	51/ .48/ <.001
PH	2.4+.11(PH)-1.9E-2(PH^2)	.35-.02(PH)+6.1E-4(PH^2)	1.78-2.77E-2(PH)-7.4E-3(PH^2)
n/R^2/p	54/ .38/ <.001	41/ .38/ <.001	41/ .51/ <.001
ERVA			
JD	3.83-9.7E-3(JD)	.57-1.9E-3(JD)	1.94-5.6E-3(JD)
n/R^2/p	18/ .71/ <.001	27/ .62/ <.001	28/ .47/ <.001
GDD	2.6-9.2E-4(GDD)	.31-1.7E-4(GDD)	1.26-64E-4(GDD)
n/R^2/p	18/ .74/ <.001	24/ .58/ <.001	24/ .56/ <.001
PH	3.85-.35(RPH*)	.67-8.6E-2(RPH)	2.5-.31(RPH)
n/R^2/p	18/.50/<.001	18/ .67/ <.001	18/.70/ <.001

Table 2.7 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) in leaves of graminoids; *Calamagrostis canadensis* (CACA), *Eriophorum angustifolium* (ERAN) and inflorescences of *Eriophorum vaginatum* (ERVA) found in diets of Seward Peninsula reindeer.

Species	NDF(%)	ADF(%)	IVTDMD(%)
CACA			
JD	24.5+.18(JD)	8.5+9.4E-2(JD)	156.8-.43(JD)
n/R^2/p	18/ .45/ .002	18/ .59/ <.001	17/ .71/ <.001
GDD	52.1+.16(GDD)	22.61+8.4E-3(GDD)	92.12-3.9E-2(GDD)
n/R^2/p	17/ .50/ .001	18/ .59/ <.001	17/ .71 <.001
PH	56.15+.82(PH)	23.61-.56(PH)	87.3-2.5(PH)
n/R^2/p	16/ .21/ .07	16/ .31/ .03	15/ .39/ .01
ERAN			
JD	100-.48(JD)+1.3E-3(JD^2)	72.02-.53(JD)+1.4E-3(JD^2)	17.86+.71(JD)-2.4E-3(JD^2)
n/R^2/p	50/ .24/ .001	53/ .37 <.001	53/ .39/ <.001
GDD	57.5-1.1E-2(GDD)+1.1E-5(GDD^2)	24.7-1.3E-2(GDD)+1.2E-5(GDD^2)	67.91+1.6E-2(GDD)-2.9E-5(GDD^2)
n/R^2/p	49/ .37/ <.001	52/ .37/ <.001	51/ .45/ <.001
PH	58.6-1.8(PH)+.18(PH^2)	25.2-1.76(PH)+.17(PH^2)	63.65+3.76(PH)-.48(PH^2)
n/R^2/p	50/ .20/ .006	53/ .27/ <.001	48/ .46/ <.001
ERVA			
JD	75.9-5.8E-2(JD)	10.7+7E-2(JD)	-93.8+2.02(JD)-.6E-2(JD^2)
n/R^2/p	18/ .39/ .018	18/ .84/ <.001	18/ .33/ .06
GDD	68.1-5.2E-3(GDD)	19.97+6.6E-3(GDD)	77.8-.013(GDD)
n/R^2/p	18/ .39/ .017	18/ .86/ <.001	18/ .40/ .016
PH	80.4-2.9(RPH)	8.55+3(RPH)	84-5.5(RPH)
n/R^2/p	18/.59/.001	18/ .92/ <.001	18/ .39/ .03

Table 2.8 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of nitrogen (N), phosphorus (P) and potassium (K) in leaves of forbs; *Equiseteum arvense* (EQAR), *Equiseteum fluviatile* (EQFL), and *Epilobium angustifolium* (EPAN).

Species	N(%)	P(%)	K(%)
EQAR			
JD	17.5-.11(JD)+1.8E-4(JD^2)	3.5-2.6E-2(JD)+4.9E-5(JD^2)	-1.8+7.8E-2(JD)-2.7E-4(JD^2)
n/R^2/p	66/ .62/ <.001	58/ .72/ <.001	58/ .73/ <.001
GDD	5.7-5.8E-3(GDD)+1.9E-6(GDD^2)	.82-1.1E-3(GDD)+4E-7(GDD^2)	3.6+7.4E-4(GDD)-2E-6(GDD^2)
n/R^2/p	56/ .84/ <.001	58/ .90/ <.001	58/ .80/ <.001
PH	2.3+.9(PH)-9.7E-3(PH^2)	.56+5.9E-2(PH)-1E-2(PH^2)	1.5+1.1(PH)-.11(PH^2)
n/R^2/p	54/ .62/ <.001	50/ .68/<.001	50/ .63/ >.001
EQFL			
JD	.86+5.6E-2(JD)-2.3E-4(JD^2)	3.07-.02(JD)+3.2E-5(JD^2)	-4.48+.11(JD)-3.5E-4(JD^2)
n/R^2/p	34/ .53/ .007	34/ .77/ <.001	34/ .85/ <.001
GDD	4.87-3.2E-3(GDD)+3.7E-7(GDD^2)	.82-1E-3(GDD)+3.6E-7(GDD^2)	3.96-6.5E-4(GDD)-1E-6(GDD^2)
n/R^2/p	34/ .70/ .001	34/ .88/ <.001	34/ .85/ <.001
PH	-7.763.6(PH)-.27(PH^2)	-93+.49(PH)-.04(PH^2)	*
n/R^2/p	24/ .49/ .03	24/ .69/ .005	**24/ 3.2/ .18
EPAN			
JD	31.87-.25(JD)+4.99E-4(JD^2)	4.12-3.2E-2(JD)+6.4E-5(JD^2)	3.3-1.1E-2(JD)
n/R^2/p	41/ .76/ <.001	41/ .77/ <.001	41/ .41/ <.001
GDD	5.49-6.6E-3(GDD)+2E-6(GDD^2)	.61-6.8E-4(GDD)+2.06E-7(GDD^2)	1.84-9.6E-4(GDD)
n/R^2/p	41/ .81/ <.001	41/ .74/ <.001	41/ .61/ <.001
PH	4.51-.68(PH)+3.14E-2(PH^2)	.53-.08(PH)+3.4E-3(PH^2)	1.5-9.6E-2(PH)
n/R^2/p	34/ .68/ <.001	34/ .79/<.001	34/ .61/ <.001

Table 2.9 Relationships between Julian Date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) in leaves of forbs; *Equiseteum arvense* (EQAR), *Equiseteum fluviatile* (EQFL), and *Epilobium angustifolium* (EPAN).

Species	NDF(%)	ADF(%)	IVTDMD(%)
EQAR			
JD	133.7-1.1(JD)+3E-3(JD^2)	95.9-.85(JD)+2.3E-3(JD^2)	14.3+.88(JD)-2.6E-3(JD^2)
n/R^2/p	65/ .62/ <.001	65/ .73/ <.001	67/ .65 <.001
GDD	32.5-1.8E-2(GDD)+1.7E-5(GDD^2)	18.7-1.4E-2(GDD)+1.4E-5(GDD^2)	83.67+1.8E-2(GDD)-2.1E-5(GDD^2)
n/R^2/p	55/ .58/ <.001	55/ .71/ <.001	57/ .66. <.001
PH	41.3-6.3(PH)+.57(PH^2)	25.2-4.8(PH)+.4(PH^2)	70.4+8.7(PH)-.82(PH^2)
n/R^2/p	53/ .48/<.001	53/ .59/ <.001	53/ .57/ <.001
EQFL			
JD	-226.1+2.5(JD)-5.9E-3(JD^2)	-71.46+.83(JD)-1.9E-3(JD^2)	-25.36+1.28(JD)-3.5E-3(JD^2)
n/R^2/p	31/ .58/ .02	31/ .75/ <.001	31/ .78/ <.001
GDD	15.46+5.3E-2(GDD)-3.1E-5(GDD^2)	10.9+2.1E-2(GDD)-1.1E-5(GDD^2)	89.53+1.3E-2(GDD)-1.6E-5(GDD^2)
n/R^2/p	33/ .66/ .01	31/ .83/ <.001	31/ .72/ <.001
PH	117-26.85(PH)+1.97(PH^2)	47.73-9.9(PH)+.77(PH^2)	*
n/R^2/p	23/ .70/ <.001	23/ .77/ <.001	**23/ 91.3/ .6
EPAN			
JD	-47.05+.34(JD)	-34.48+.25(JD)	174.94-.53(JD)
n/R^2/p	41/ .66/ <.001	41/ .64/ <.001	41/ .43/ <.001
GDD	6.25+.02(GDD)	4.23+1.5E-2(GDD)	93.11-3.6E-2(GDD)
n/R^2/p	41/ .69/ <.001	41/ .63/ <.001	41/ .49/ <.001
PH	9.02+2.69(PH)	5.87+1.99(PH)	88.95-5.14(PH)
n/R^2/p	34/ .54/ <.001	34/ .54/ <.001	34/ .51/ <.001

Table 2.10 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of nitrogen (N), phosphorus (P) and potassium (K) in leaves of forbs; *Pedicularis species* (PESP), *Hippuris vulgaris* (HIVU), and *Caltha palustris* (CAPA). * Regression equation not significant or available. ** Data presented as $n/\bar{x}/s_{\bar{x}}$.

Species	N(%)	P(%)	K(%)
PESP			
JD	4.96-1.28E-2(JD)	*	*
$n/R^2/p$	19/ .27/ .04		
GDD	3.24-1.4E-3(GDD)		
$n/R^2/p$	19/ .43/ .008		
PH	*		
$n/R^2/p$	**19/ 2.46/ .08		
HIVU			
JD	2.92-4.3E-3(JD)	.49-9.5E-4(JD)	2.54-5.4E-3(JD)
$n/R^2/p$	43/ .14/ .06	43/ .20/ .005	41/ .22/ .004
GDD	2.4-5E-4(GDD)	.37-9.6E-5(GDD)	1.78-4.3E-4(GDD)
$n/R^2/p$	43/ .21/ .02	43/ .23/ .003	41/ .19/ .01
PH	*	.38-2.9E-2(PH)	1.73-7.7E-2(PH)
$n/R^2/p$	**43/ 2.2/ p = 0.11	43/ .29/ .001	41/ .10/ .08
CAPA			
JD	5.56-1.5E-2(JD)	2.1-1.43E-2(JD)+2.4E-5(JD^2)	6.05-1.6E-2(JD)
$n/R^2/p$	20/.32/ .01	23/ .58/ <.001	23/ .41/ .004
GDD	3.49-1.3E-3(GDD)	.71-9.7E-4(GDD)+4.27E-7(GDD^2)	3.53-8.4E-4(GDD)
$n/R^2/p$	20/ .54/ <.001	23/ .81/ <.001	23/ .28/ .02
PH	3.75-.15(PH)	*	*
$n/R^2/p$	20/ .31/ .014	**23/ .33/ .026	**23/ 3.06/ .098

Table 2.11 Relationships between Julian date (JD), growing degree days (GDD) and phenology (PH) and percentage (%) of neutral detergent fiber (NDF), acid detergent fiber (ADF) and in-vitro true dry matter digestibility (IVTDMD) in leaves of forbs; *Pedicularis species* (PESP), *Hippuris vulgaris* (HIVU), and *Caltha palustris* (CAPA). * Regression equation not significant or available. ** Data presented as n/ $\bar{x}$ / $s_{\bar{x}}$.

Species	NDF(%)	ADF(%)	IVTDMD(%)
PESP			
JD	-31.73+.33(JD)	-22.69+.22(JD)	154.31-.4(JD)
n/R^2/p	19/ .83/ <.001	19/ .85/ <.001	19/ .73/ <.001
GDD	14.56+.31E-2(GDD)	9.12+2.1E-2(GDD)	*
n/R^2/p	19/ 0.80/ < 0.001	19/ 0.80/ < 0.001	**19/ 78.0/ 1.5
PH	*	*	*
n/R^2/p	**19/ 29.5/ 1.4	**19/ 19.17/ 0.96	
HIVU			
JD	19.66+6.5E-2(JD)	*	*
n/R^2/p	43/ 0.18/ 0.02	**43/ 23.7/ 0.5	**43/ 81.94/ 0.9
GDD	28.61+5.6E-3(GDD)	21.74+3E-3(GDD)	*
n/R^2/p	43/ 0.19/ 0.01	43/ 0.11/ 0.07	
PH	25.47+2.48(PH)	*	*
n/R^2/p	43/ 0.12/ 0.06		
CAPA			
JD	202.45-1.93(JD)+5.1E-3(JD^2)	111.56-1.04(JD)+2.7E-3(JD^2)	117.65-.17(JD)
n/R^2/p	23/ 0.32/ 0.05	23/ 0.43/ 0 .01	23/ 0.35/ 0.008
GDD	*	*	94.28-1.4E-2(GDD)
n/R^2/p	**23/ 20.57/ 0.92	**23/13.08/ 0.43	23/ 0.43/ 0.003
PH	*	*	77.54+5.4(JD)-.57(JD^2)
n/R^2/p			23/ 0.50/ 0.005

CHAPTER 3

Influence of regional landscape diversity of the Seward Peninsula, Alaska on diet, tissue and serum mineral values and production of reindeer (*Rangifer tarandus tarandus*).

Abstract

The management of domestic reindeer (*Rangifer tarandus tarandus*) on designated grazing allotments (ranges) on the Seward Peninsula, Alaska is based on landscape units classified and mapped as ecological site descriptions (ESD). Reindeer are moved to summer, winter and calving areas on ranges and allowed to graze freely but each range is composed of a unique combination of ecological sites. Reindeer appear to be very selective, both temporally and spatially in what they eat, but composition of the diet was not correlated with the composition of ESDs making up a range. Composition of forage species making up diets of reindeer varied significantly across ranges, but there were common seasonal shifts from primarily lichen in the spring and winter to willows and sedges during the summer months and then shifting back to lichens during fall and winter. Willow, sedge and *Equisetum* species dominated the summer diets of reindeer even though other shrubs such as dwarf birch, blueberry and grasses were quite common in many of the ranges. The proportion of sedges increased in the spring diet reflecting both the emergence of cotton grass flowers and the emergence and elongation of leaves of other sedge species.

Blood samples collected in this study indicate small variation in serum mineral concentrations among individuals within a herd, but showed significant differences

among ranges suggesting landscape differences in the intake of nutrients. Serum and tissue values of reindeer varied significantly between sex and season, reflecting both differences in diet and physiological state, but could not be predicted by the composition of ecological sites making up a range. For the most part, serum and tissue values fell within the expected normal values for ruminants, and production, estimated by calf weight and recruitment, was good to excellent in all herds. The landscape effect on dietary profile, serum and tissue mineral values found in these herds is likely at a scale finer than expressed by ecological site. However, results of this study may provide a baseline for comparison to future diets or serum values of reindeer on the Seward Peninsula if large scale landscape changes occur or can provide benchmark values to evaluate other *Rangifer* populations that may be nutritionally compromised.

Introduction

Rangifer populations typically live in arctic and alpine environments that are particularly diverse in physiographic features which lead to varied vegetation communities exhibiting an assortment of nutritional characteristics. The diet selection by reindeer in turn is highly labile because it is influenced concurrently by seasonal physiological demands, and diverse attributes of the forage (Trudell and White, 1981; Marell and Edenius, 2006; Danell *et al.*, 1994; Klein, 1990).

Domestic reindeer (*Rangifer tarandus tarandus*) from Russia were introduced to the Seward Peninsula, Alaska at the turn of the 19th century to be managed by the local people for sustenance and income. Populations quickly grew to over 130,000 animals (Stern *et al.*, 1980) which suggests excellent grazing on the Seward Peninsula. Currently, individual producers are granted permits for grazing reindeer on public lands of the Seward Peninsula as designated and exclusive allotments (hereafter called ranges). Since herbivores are the product of their grazing environment, we can study the effect of the regional distinctiveness of these ranges on the attributes of locally raised reindeer. Plant community composition should influence the diets of reindeer and in turn productivity.

The geology of the Seward Peninsula is diverse, and complex (Sainsbury, 1974) and the interaction of soil, plant species, climate and phenology produce a great heterogeneity in vegetation communities and the nutritional characteristics of available forage (Finstad and Kielland, 2008). Chemical characteristics, and thus their value and preference to foraging reindeer, vary not only across species but temporally as well (Kuropat and Bryant, 1983; Klein 1990; Finstad and Kielland 2008). Reindeer vary their

intake of energy and nutrients during a short growing season by foraging in patches and on species according to plant availability and quality (White and Trudell, 1980; White, 1983). Therefore, it is expected that reindeer will be selective in the plants they consume at any given time during the growing season. The nutrient flux between soil, plant and animals will therefore be a dynamic one where reindeer grazing in a unique habitat (range) will have a distinctive temporal and spatial diet. Whereas the diets of reindeer and caribou have been examined in many grazing systems across the circumpolar North, they have not been studied thoroughly on the Seward Peninsula.

The Seward Peninsula has been divided into 15 distinct ranges consisting of state and federal public lands averaging 400,000 ha in size (Fig. 3.1). Individuals or families of Native Alaskan origin have been granted exclusive grazing permits for these ranges, but developing a range management plan which includes identification of seasonal grazing areas and a rotational grazing schedule is a condition of the permit. To meet the mandates of land managers of sustainable land use and to ensure herd productivity, a producer must know the seasonal diet selection and physiological responses of reindeer to temporal and spatial differences in vegetation across their ranges. In this way, areas within a range containing higher proportions of preferred forage can be identified and producers can respond by distributing their animals across the range accordingly. Current management of public rangelands in the United States is based on the use of ecological site descriptions (ESDs) Ecological site descriptions replace the traditional range site descriptions that focused primarily on forage production in favor of ecological site descriptions that include geology, soils, climate, hydrology and physiographic features as

well as forage production. They are used to stratify the landscape and organize ecological information for purposes of monitoring, assessment, and management of rangeland. An ecological site is distinctive kind of land with specific soil and physical characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances. The rangelands of the Seward Peninsula were classified and mapped by the Natural Resource Conservation Service (NRCS) as 39 distinct ecological sites containing 113 different species of vascular plants, lichens and mosses (Swanson *et al.*, 1985; Finstad *et al.*, 2007). These ecological sites are the basis for management of Alaskan rangeland but their effectiveness as a range management tool for reindeer producers has never been evaluated.

Adequate mineral nutrition of ruminants is required for forage digestion, growth or replenishment of tissues, reproductive performance and a variety of metabolic functions. Ultimately, it is the interaction of the soil, plant species and diet that influences the pattern of mineral nutrition for a ruminant population. Reindeer on the Seward Peninsula are presented with a diversity of forage species on which to graze which have widely differing mineral compositions across species and within species during various phenological stages (Finstad and Kielland, 2008). The range of mineral concentrations found in reindeer tissue generally reflects dietary intake levels of minerals (Hyvärinen *et al.*, 1977; Ropstad *et al.*, 1997). Deficiencies and imbalances of minerals has been shown to influence animal condition, fertility, productivity and mortality in Scandinavian

reindeer (Hyvärinen *et al.*, 1977; Säkkinen, 2005) and have been reported for free ranging moose in Alaska (Franzmann *et al.*, 1975).

Variation in blood mineral composition often reflects changes in the diet (Guthrie, 1971) and has been shown to vary in captive and free-ranging Fenno-Scandinavian reindeer (Bjärghov *et al.* 1976; Hyvärinen *et al.*, 1975, 1977; Halse *et al.*, 1976; Nieminen and Timisjärvi 1983; Nilsson, 2000). Blood chemical constituents have also been used to estimate herd production such as calving success (Milner *et al.*, 2003).

Reindeer are also raised under captivity across North America where they do not have access to rangelands but instead are fed a formulated ration. Producers feeding an artificial ration are particularly interested in establishing baseline serum and tissue concentrations of minerals for reindeer in a natural grazing environment to be used to ensure maximum growth and reproduction (Reindeer Owners and Breeders Association, 2003). Producers of reindeer in captive management systems outside of Alaska are particularly concerned with dietary levels of copper (Cu) and selenium (Se).

Copper is an essential trace element (required for enzyme systems, iron metabolism, integrity of the central nervous system, reproduction and immune responsiveness) and has been suspected to be deficient in some non-Alaskan reindeer herds. Baselines of tissue values of free-ranging reindeer that forage in ecologically suitable and nutritionally diverse habitats and exhibit good production can be used to assess the presence of nutrient deficiencies within a group of reindeer fed a formulated ration. Reindeer on the Seward Peninsula exhibit high body weights and growth rates when compared to other circumpolar *Rangifer* populations (Finstad and Prichard, 2000)

and may be used as the baseline model for other herds. Establishing mineral concentrations in tissues of animals that exhibit good growth and reproduction will set standards to identify potential nutritional problems in populations whose tissue values fall outside normal values. Supplementation may increase dietary levels to ameliorate deficiency syndromes.

Objectives

The present study aimed to (1) describe the distinctiveness of reindeer ranges by percentage of ecological sites contained therein; (2) determine the diets of reindeer grazing within ranges and compare to composition of ecological sites of ranges across the Seward Peninsula; (3) compare the mineral status of blood serum and liver in reindeer across ranges; and (4) evaluate calf growth and calf: cow ratios as indices of production in relation to ecological site composition. If ecological site composition could predict productivity of reindeer across ranges then this relationship could be used by reindeer producers on the Seward Peninsula to distribute animals on ecological sites that ensure good nutrition and production of their herds.

Study Site

The Seward Peninsula projects into the Bering Sea between Norton and Kotzebue Sound on the western coast of Alaska (Fig. 3.1). The entire peninsula is 330 km long and 145 to 225 km wide. The Seward Peninsula has extensive river systems, the major ones include the Koyuk, Kuzitrin, Niukluk, Fish, Kiwalik, Buckland and Agiupuk Rivers that are drained by catchment basins of up to 1600 km^2. The topography is diverse ranging

from low lying wetlands along the coast and interior basins rising abruptly to rugged mountain ranges with peaks to 1460 m. Four mountain ranges, generally trending east to west bisect the interior of the peninsula with the most prominent are the Kigluaik Mountains. Other mountains include the Bendeleben, Darby and York Mountains (Fig. 3.1).

The bedrock is chiefly metamorphic with massive granitic intusions. The Seward Peninsula soils are classified as Histic Pergelic Craquepts, Pergelic Cryaquepts, Typic Cryochrepts, Pergelic Cryumbrepts, Lithic Cryorthents, and Pergelic Cryorthents (Van Patten, 1990). On the upper slopes of hills and mountains, frequent freezing and thawing fractures the underlying rocks and creates large areas consisting of mostly angular rocks. The fine materials and the smaller rocks are washed downhill by flowing water and by gravity, leaving the larger rocks behind. Soils which develop on slopes are usually better drained and warmer than soils in lower zones and given sufficient moisture will support the tallest vegetation, usually shrubs. The Seward Peninsula is in the zone of continuous permafrost and the surface layer thaws to various degrees during the growing season giving rise to a shallow biologically active area. The surface water does not move through the active layer but instead is concentrated near the surface. Because the active layer is saturated, it is churned and stirred during the annual freeze-thaw cycle inhibiting the formation of soil horizons. As a consequence of permafrost, the dominant soils of most Seward Peninsula lowlands are poorly developed, waterlogged, and cold. Since the amount of soil available to support plant growth is limited in depth, root systems tend to be shallow.

On much of the Seward Peninsula, differential frost heaving creates hummocks. These hummocks are very dry on their tops, drained along their sides, but contain pools of water at their bottoms resulting in a variety of different growing environments for plants within a very small area. Each one of these distinctive soil environments generally leads to development of characteristic plant communities. As a result, the vegetation of the Seward Peninsula is highly variable and consists of a patchwork of distinctive plant communities. The vegetation can be classified as tundra (Walker, 2003), but species composition within these communities is not dominated by a distinctive plant growth form. It varies dramatically along microphysiographic gradients as well as larger regional and latitudinal scales (Billings, 1975; Bliss, 1981; Wielgolaski *et al.*, 1975).

Acidic volcanic rock and basic limestone uplands support separate and distinctive vegetation communities. Shrub communities of willow and alder are well developed on low rolling hills in the southern Seward Peninsula, while the same terrain to the north supports mainly tussock tundra. Plant communities transition between maritime (wet) tundra along the coast to subarctic (dry) tundra inland to alpine tundra in the higher elevations (Walker, 2003). Much of the tundra vegetation is Asian in character and similar to Chukotka, while many species common in Alaska do not occur east of the Mackenzie Delta (Billings and Mooney, 1968; Wielgolaski *et al.*, 1975; Bliss, 1981). Tussock-forming *Eriophorum vaginatum* is the dominant plant on the Seward Peninsula but in warmer areas is replaced by the sedge *Carex bigelowii*. Various willow species dominate the extensive riparian zones that finger across the Seward Peninsula. Low

shrubs such as *Vaccinium*, *Ledum* and *Betula* are common in well drained upland-heath areas.

This study was conducted on six allotted reindeer ranges extending from the tip of Cape Darby, north to the Kougarak Mountains and the windswept marshes of Shishmaref Inlet (Fig. 3.1). The Gray range consists of the Fish River drainage system and is dominated by the Fish River Delta and the Kwiktalik and Darby Mountains. Mountains and hills surround the Fish River Delta forming a solar basin, which results in warmer temperatures during spring and summer than outlying uplands (RRP unpublished temperature data). Many small lakes, ponds, and creeks are present giving rise to abundant growth of emergent and semi-emergent vegetation. Riparian shrubs (willows) are common in the lowland drainages.

The Davis Range consists of the coastal plains near Nome where grasses dominate to the more mountainous area to the north where woody shrubs predominate. The majority of the range is rolling valleys containing rivers, streams and lowlands that support a large number of deciduous shrubs.

The Kakaruk Range extends from the Sinuk River in the south to Imruk Basin to the north, and is characterized by the sharp relief extending from low coastal or inlet areas to the steep and rugged Kigluaik Mountains. Imruk Basin is surrounded by uplands and the Kigluaik Mountains forming a solar basin characterized by warmer summer temperatures than surrounding uplands. The Kigluaik Mountains shape the local weather patterns by influencing wind and precipitation patterns. The range is characterized by a windswept coastal area and warm solar basin to steep mountainous slopes.

The Noyakuk range extends from the Kigluaik Mountains, north to the Kougarak Mountains and is dominated by willow species in the floodplain surrounding the Imruk basin, a large brackish lake in the southern portion of the range, and vast areas of dry tundra extending northward to the Kougarak Mountains. Imruk Basin and the Kougarak Mountains are the dominant topographical features of the landscape. Vegetation consists of sedges and grasses in the lowlands, shrubs on the mid-slopes, progressing to lichen mat on the higher elevations.

The Olanna range extends from the York Mountains to the Agiapuk River. Much of the range consists of barrens and upland tundra in the hills and tussock tundra in lowland The Olanna range consists of wet tundra surrounding Brevig Mission merging with dry tundra on lower slopes of hills and mountains to the north and east, while upper slopes are bald limestone or barren. Climate is influenced by onshore winds from Grantley Harbor with cold persistent winds in winter and cool wet, foggy summers.

The Weyiouanna range is predominately windswept tussock tundra interspersed with wet and dry tundra. There are extensive lowland shrubs consisting of riparian willows and dwarf birch. There are extensive shrub hillsides surrounding Ear Mountain, the singular high point of the surrounding lowlands.

Methods

Range descriptions

Individual reindeer ranges were described according to percentages of ecological sites (ecosites) found in each range by uploading the digitized Vegetation Map of the

Reindeer Ranges of the Seward Peninsula (Natural Resource Conservation Service data; Swanson *et al.*, 1985) and range boundaries into Arcview™. Ecosites found in each range were classified according to dominant growth form found in species composition and cover percentage descriptions; willows (W), shrubs other than willow (Sh), grasses (G), sedges (S), and lichen (L). Sites containing mostly non-forage species such as tussock tundra but containing a few graminoid and forb species eaten by reindeer were classified as limited (Lm). Ecosites containing predominately evergreen trees (spruce), and alder shrubs, or were barren of vegetation were pooled into a barren (B) category (Swanson *et al.*, 1985). Ecosites with same class designations were pooled to estimate the percentages of plant growth form found in each range allotment. Statistical analyses were carried out using the GLM and MIXED procedures Systat 8.0 (Systat 8.0, 1998). The model for comparing differences in percentage of ecosite classification included the fixed effect of range. Significance was defined as $p \leq 0.05$.

Diet composition

Groups of reindeer were located on each range in June 1996 either through radio telemetry surveillance flights or observation reports from herders. Female reindeer from the Weyiuoanna, Olanna, Noyakuk, Davis and Gray herds were fitted with Telonics™ Very High Frequency (VHF) radio collars in previous years to support other studies. An airplane was equipped with a Telonics™ scanner-receiver to assist with the location of radio-collared reindeer. A ground crew traveled to sites and visually located reindeer groups on the respective ranges. Five to ten fecal pellets from 10 distinct pellet groups were collected and pooled into one sample. If enough pellet groups were found up to

three pooled replicate samples were collected from each site. Pellet samples were also collected from the Olanna and Gray reindeer herds from April 1996 until March 1997, and the Davis and Gray reindeer herds from April 1997 until March 1998 and during May 1997 through Feb 1998 on the Noyakuk range. Samples were allocated by season: June, July, Fall (Sept-Oct), Winter (Nov.-March) and Spring (April-May). Samples were placed in a drying oven for 48 hours at 65 C^0. The samples were sent to the Wildlife Habitat Laboratory, Washington State University for a 25 view, level A, diet composition analysis (Todd and Hansen, 1973). Since digestibility of forage will influence the proportion of nondigestible components found in the feces, diet percentages of each forage class were adjusted according to seasonal digestibility functions taken from Finstad and Kielland, 2008. Adjusted diet composition data expressed as proportions were transformed to the arcsine of the square root to meet assumptions of normality for ANOVA (Arcsine trans. proc. Systat 8.0, 1998). Multivariate Analysis of Variance (MANOVA) was used to test for differences in diet according to range and season (Systat 8.0, 1998). Range and season was used as factors and the percentage of each forage class found in the diet; willows, shrubs, grasses, sedges, equisetum, forbs, lichen, moss, rhizomes was used as dependent variables. The general linear models procedure (GLM) (Systat 8.0, 1998) used to test for a significant relationship between ecosite compositions expressed as habitat class of a range and diet of reindeer on that range. Totals of same ecosite classification within a range was treated as a continuous independent variable with total percentage of plant growth form found in diets of reindeer on that range as dependent variable.

Serum and tissue sampling

Reindeer on the Seward Peninsula, Alaska are brought into corral systems biannually (summer and winter) for censusing, eartagging, veterinary care and animal husbandry procedures. Blood was collected via venapuncture from 20 randomly selected yearling male and female reindeer restrained in a chute at each summer handling and at the Gray, Olanna and Weyiuoanna winter handlings of 1997. Only five yearling females and one male sample were collected in winter from the Noyakuk herd due to insufficient number of yearling animals. Blood was transferred to blue-top sterile vacutainers with no additive and placed in an insulated carrying container to keep at a constant cool temperature. Five samples of each cohort were collected and transferred to pink-top vacutainers containing EDTA for Se analysis. The blood samples were transported to a laboratory facility in Nome, Alaska where the blood was centrifuged at 2000 rpm for 10 minutes and serum pipetted to cryogenic serum vials. Transportation and handling time prior to serum collection was 4-12 hours for the Davis, Gray and Olanna summer samples but was between 8-18 hours for samples collected during the winter and at the more remote handling sites. Serum samples showing signs of hemolysis (pink coloration) were discarded. The serum was sent to the Analytical Sciences Laboratory, Holm Research Center, University of Idaho and analyzed for concentrations of zinc (Zn), phosphorus (P), iron (Fe), magnesium (Mg), copper (Cu), and calcium (Ca) and the whole blood was analyzed for concentration of selenium (Se). For further information on minerals in ruminant nutrition see Appendix C.

Liver tissue samples were collected from slaughtered steers and adult females during January or February 1997. Approximately 50 grams of liver from the caudate lobe of the liver were collected by personnel wearing sterile latex gloves, and all stainless steel collection and dissection tools were cleaned with ethanol between collections of samples. All samples were placed in Whirlpak™ bags, immediately frozen, and transported to the University of Alaska Fairbanks. Liver samples were dried at 100^{O}C for 72 hrs ground using a Wiley™ mill with a resin 20mm mesh, placed in Whirlpak™ bags and sent to the Soil and Plant Analytical Laboratory in Palmer, Alaska where they were analyzed for concentration of Cu reported as μg/g dry matter (DM). For further information on the calibration of concentrations of liver Cu reported as either wet weight (WW) or on a DM basis see Appendix D.

Multivariate Analysis of Variance (MANOVA) was used to test for season and range differences in serum mineral values. Herd, season and sex were used as factors whereas serum mineral concentrations of Fe, Mg, Cu, Ca, P, Zn and Se were used as effects. (Systat 8.0, 1998).

Animal productivity

Body weights of calves and calf:cow ratios were collected at the Davis, Gray, Noyakuk Olanna and Weyiouanna herds by University of Alaska Fairbanks – Reindeer Research Program (UAF-RRP) staff during 1996 summer handlings. Calves were held by a handler on a platform mounted on a Tru-test™ livestock scale to determine body weight. All animals were individually run through a chute, restrained, identified to ear tag number, sex and age and released. Presence or absence of an udder was determined for

each female in some herds. Since dates of reindeer handlings varied from June 18th to July 1 across Seward Peninsula range allotments, calf weights had to be standardized to a consistent handling date. To due that, June 25th was selected as the mean handling date occurring in all years across all ranges. Many herders conducted more than one handling (bull vs. female handlings) during the summer and all calves were weighed at each handling so rates of weight gain (kg day^{-1}) could be determined by comparing early handling mean calf weights to subsequent handling mean weights. All calf weights taken at all handlings from 1989 to 1997 were pooled and regressed to determine a grand mean female and male calf growth rate for the Seward Peninsula. The growth coefficients (kg day^{-1}) were used to standardize calf weights from handlings not occurring on June 25th. Calf /cow ratios of each June handling were estimated using total number of calves and adult females (over two years of age) seen during that handling.

Mineral concentrations of Seward Peninsula forage were taken from Finstad and Kielland (2008).

Results

Ecological site composition across ranges

Percentages of ecological sites in range allotments varied considerably across the Seward Peninsula (Table 3.1). There was a significant difference in ecological site composition due to range when data was arc-sine transformed (F-Statistic $_{(21, 128)} = 2.9$, $p < 0.01$), (Table 3.1) and there was a significant difference due to range when ecological sites were categorized into habitat classes (F-Statistic $_{(6, 35)} = 2.9$, $p < 0.05$); (Table 3.1).

Diet Composition

To facilitate interpretation of the results, the identified plant material in the feces was grouped (Table 3.2) according to plant growth form. Leaves, stems and catkins of all *Salix* species were grouped together and all other deciduous and evergreen shrubs i.e. *Betula, Dryas, Vaccinium* were grouped as shrubs. Leaves and inflorescences of *Carex* and *Eriophorum* were grouped as sedges and all other graminoids grouped as grasses. *Equiseteum* spp., which were the dominant forbs found in the diet, were classified in one group while all other forbs were grouped together. Lichens were not identified to species but were grouped together as were any rhizome materials found in the feces.

Spring (April – May)

Lichens dominated in spring diets (56.0 to 68.8%; Table 3.2) followed by mosses (7.3 to 10.4%), sedges (7.8 to 9.5%) and shrubs (1.9 to 10.2%). Wintergreen parts of sedges and newly emerging *Eriophorum vaginatum* flowers and stems or leaves of evergreen shrubs were found in the spring diets of Seward Peninsula reindeer. Stem material and catkins of willows comprised 2.4 to 4.5% (Table 3.2) of the spring diet across ranges and rhizome material began to appear in reindeer diets (Table 3.2).

June (Green-up)

Green-up was marked by a large increase in the percentage of willows (13.9 to 41.4%) and sedges (7.8 to 26.9%; Table 3.2) in diets across ranges. The percentage of lichens declined markedly, but was still found in substantial amounts (25.9 to 49.4%). Grasses were found in moderate proportions (1.8 to 7.4%) while neither forbs nor rhizomes were found in any considerable proportion of the June diet (Table 3.2).

July (Summer)

Salix, sedges and lichen dominated the July diet across ranges (Table 3.2.) but the percentage of forbs increased in the diet most likely reflecting their emergence and growth during this time period. There was a trend for the percentage of lichen to increase slightly in the July diet over the June diet (40.5 to 62.3%; Table 3.2). Shrubs other than *Salix*, grasses and mosses were generally found in lower percentages of July diets than June diets (Table 3.2).

Fall

In the fall there was a substantial shift away from consumption of willows, shrubs and grasses to a diet that included primarily lichen (69.0 to 81.3%) and some sedges (6.7 to 10.0%) across all ranges (Table 3.2). A small percentage of *Equisetum* and other forbs and no moss were found in the fall diet.

Winter

Lichens continued to be the dominant growth form consumed in winter comprising 64.7 to 76.6% of the diet (Table 3.2). Further, the percentage of mosses increased in the diet while grasses decreased. Sedges comprised 2.5 to 11.5% of the winter diet likely as wintergreen portions of *Carex aquatilus and Eriophorum angustifolium.* Salix was consumed most likely as stems (1.5 to 5.4%) and shrubs as stems and evergreen leaves of *Vaccinium* (2.3 to 7.7%) in winter (Table 3.2). Graphical display of seasonal diets of reindeer can be seen in Appendix E.

Percentages of ESD classes making up a range were not a good predictor of percentage of plant growth form in reindeer diets ($p = 0.14$; $R^2 = 0.08$) suggesting

reindeer were selecting forage within a range at a scale other than represented by ecological site.

Serum mineral values

There were significant differences in serum mineral levels due to range (F-Statistic $_{(40, 647)} = 8.63$, $p < 0.01$) in summer and in winter (F-Statistic $_{(16, 62)} = 8.22$, $p < 0.01$), (Table 3.3). There were significant differences in summer serum values due to sex. Serum concentrations of Fe on the Davis range, Mg and Ca on the Gray range, P on the Noyakuk range and Zn on the Olanna range were all significantly higher in males than females. Serum concentrations of Zn, P, Mg, Ca and Na were all significantly higher in females than males on the Weyiouanna range (Table 3.3). There were significant differences in winter serum values due to sex. Serum concentrations of P and Cu were significantly higher in males than females on the Gray range. Serum concentrations of Mg, Ca and Se were significantly higher in females than males on the Gray range (Table 3.3). There were significant differences in serum mineral values due to season. Reindeer serum concentrations of Zn on Gray and Olanna ranges, P concentrations on the Gray, Noyakuk, Olanna, and Weyiouanna ranges, Cu serum concentrations on the Noyakuk range, Fe concentration on the Olanna range, Mg concentrations on the Gray and Olanna ranges, Ca concentration on the Olanna range and Na concentration on the Weyiouanna range were all significantly higher in summer. Serum Na concentration of animals on the Gray and Se concentrations on the Gray, Olanna and Weyiouanna ranges were all significantly higher in winter (Table 3.3).

Copper concentrations in liver

There were significant differences in liver copper concentrations across ranges (F-statistic $_{(3, 94)}$ = 16.6, $p < 0.01$). Mean copper concentration of liver in reindeer from the Davis herd was 59.6 μg/g DM ± 5.2; Gray 129.1 μg/g DM ± 13.2; Noyakuk 101.3 μg/g DM ± 9.1; and Weyiuoanna 15.0 μg/g DM ± 3.0.

Herd productivity

Mean June growth rate of male calves (0.36 kg day $^{-1}$), (n = 7096; $p < 0.01$; R^2 = 0.52) was higher compared to that of female calves (0.32 kg day $^{-1}$) (N = 8166; $p < 0.01$; $R^2 = 0.52$). There were significant differences in June 25th male calf weight (N = 2115; F-Statistic $_{(4, 2110)}$ = 147.7; $p < 0.01$) and June 25th female calf weight (N = 2551; F-Statistic $_{(4, 2546)}$ = 212.8; $p < 0.01$) due to range (Table 3.4).

Discussion

Across a range of habitats and geographic regions it has been shown that the diet composition of reindeer changes seasonally and spatially, according to plant species availability, their phenological development and nutritive value (Skogland, 1985; Klein, 1990). The diet selection of reindeer on the Seward Peninsula varied across ranges and exhibited seasonal shifts from primarily lichen in the winter/spring to willows and sedges during the summer months. Diets shifted back to lichens during autumn. Lichen was a major component of the diet both in summer and winter. This suggests reindeer will consume considerable lichen in summer when abundant. Range utilization checks by NRCS and Bureau of Land Management (BLM) found substantial lichen biomass in

ecological sites on all ranges (NRCS and BLM annual reports 1997, 1998). The preference and dominance of lichens in the winter diet of reindeer when available is clearly established (Danell *et al.*, 1994) even though they contain extremely low levels of nitrogen (Pulliainen, 1971; Nieminen and Heiskari, 1989) and minerals (Hyvärinen *et al.*, 1977). Reindeer are capable of urea recycling during winter to improve nitrogen balance but the inclusion of shrubs, sedges and mosses in the winter diet of Scandinavian reindeer helped to maintain nitrogen balance and carcass mass (Tyler *et al.*, 1999; Mathiesen *et al.*, 2000). Seward Peninsula reindeer consume considerable amounts of shrubs and sedges during winter (Table 3.2) which may provide nitrogen and minerals to an energy-rich lichen diet. The bases of the leaves of *Carex* and *Eriophorum* and some *Equisetum spp* maintain live, green tissue during winter. Storeheier *et al.* (2002) found that wintergreen parts of these graminoids and evergreen shrubs (species that are also commonly found on the Seward Peninsula) had a high concentration of crude protein and minerals. These species occur concurrently in some Seward Peninsula ecological sites (Swanson *et al.*, 1985) and may provide a diet rich in energy, protein and minerals to support the relatively high body masses of Seward Peninsula reindeer during winter (Finstad and Prichard, 2000).

Surprisingly, the proportion of moss in the winter and spring diets was higher than would be expected of productive reindeer foraging on ranges with a high availability of lichens, evergreen sedges and shrubs (Table 3.2). Mosses are nearly indigestible (IVTDMD = 21.1% ± 1.4; UAF-RRP unpublished data; Ihl and Barboza, 2007) and should only be selected by reindeer as forage as a last resort. Moss does not appear to be

incidentally eaten with lichen (Thompson and McCourt, 1981) since there is no correlation between proportions of lichen and moss in the diet of Seward Peninsula reindeer (Table 3.5). Many species of microorganisms disappear in the rumen of reindeer in winter because they consume a homogeneous lichen diet. (Orpin *et al.*, 1985; Aagnes *et al.*, 1995). Lichens are very digestible and may have a shorter retention time in the rumen than the generation time for many rumen microorganisms. Ingesting nondigestible forage would create and ensure the presence of a fiber mat in the rumen as an environment for microorganisms, especially for protozoans that may have a generation time of up to 16 hrs (Karnati et al, 2007), to maintain adequate populations for fiber degradation (Van Soest, 1994). The emergence of a wide variety of forage plants is very abrupt on the Seward Peninsula in spring and quality of forage increases very rapidly (Finstad and Kielland, 2008). To effectively digest the diversity of forage plants emerging during spring, substrate specific microorganisms are needed to repopulate the rumen. Reindeer may consume moss to promote the formation of a fiber mat in the rumen as a refuge or "life raft" for species of microflora that may be needed as "seed stock" to quickly repopulate the rumen in spring when diets diversify.

The spring diet for Seward Peninsula reindeer is particularly important because of nutrient demands of calving and lactation in females and antler growth in males. Changes in forage availability that increase energy intake of reindeer and caribou during calving increase milk production and body condition (Rognmo *et al.*, 1983). Reindeer in the Seward Peninsula calve in late April (Chetkiewicz, 1993), coincident with snowmelt and emergence of inflorescences of *Eriophorum vaginatum,* (Britton, 1966; Walker *et al.*,

1982; Cebrian, 2005; Finstad and Kielland, 2008) and is an important forage plant for reindeer and caribou (Thompson and McCourt, 1981; Kuropat, 1984). The proportion of sedges continues to increase in the spring diet of Seward Peninsula reindeer reflecting the emergence and elongation of leaves of other sedges such as *Carex bigelowii* and *Eriophorum angustifolium* (Finstad and Kielland, 2008). Reindeer with access to these high quality forages produce more milk (Chan-Mcleod *et al.,* 1994) and recover faster from winter loss of body condition (Adamczewski *et al.,* 1987; Chan-Mcleod *et al.,* 1994). With greater milk production from the mother, calf growth increases (Loudon and Kay 1984, White and Luick, 1984), which in turn promotes higher calf survival (Guinness *et al.*, 1978; Skogland, 1985). After weaning, intake of high energy forage increases calf growth (Verme and Ozoga, 1980) which greatly affects the probability of reproducing in females at two years of age (Adams and Dale, 1998). The high proportion of lichen in winter and lichen and graminoids in the spring diet of Seward Peninsula reindeer is probably a contributing factor to the relatively high calf weights seen on the Seward Peninsula compared to other reindeer populations (Finstad and Prichard, 2000; Reimers, 1983).

Although the summer diets contained a diversity of species, reindeer appear to discriminate among forages. Willows, sedges, and *Equisetum* dominated the summer diets of reindeer even though other shrubs such as dwarf birch and *Vaccinium* and grasses are quite common in many of the ecological sites (Swanson *et al.*, 1985). Dwarf birch, *Vaccinium* and grasses have been reported as major forages for other reindeer and caribou populations, but willows and sedges may have been preferred in this study

because of their relatively high abundance and high nutritional value (Finstad and Kielland, 2008). Willow, sedge and *Equisetum* species found during the summer months are highly digestible and contain high concentrations of protein and minerals (Finstad and Kielland, 2008) with low to moderate levels of anti-herbivory compounds (Kuropat, 1984). This high protein and mineral diet during summer is probably a factor responsible for the high body weight and growth rates (Finstad and Prichard, 2000) and high reproductive rates found in Seward Peninsula reindeer (Prichard *et al.*, 1999).

The diets of reindeer varied throughout the year, likely to meet physiological demands due to elevated concentrations of steroids and growth factors (Suttie and Webster, 1995). The summer diets of Seward Peninsula reindeer were dominated by the high protein forages such as willows and sedges to support the growth of lean tissue, organs, antlers, and hair coat (Klein, 1970). Reindeer began to consume a higher proportion of graminoids and lichen during fall (Table 3.2) even though high protein willow leaves and forbs were still available (Finstad and Kielland, 2008). After lean tissue, hair and antler growth during summer reindeer must choose a diet high in energy that will support fat deposition prior to winter (Allaye-Chan, 1991). Lichens and graminoids on the Seward Peninsula contain relatively high concentrations of the fiber component, hemicellulose, which is a digestible energy source commonly consumed by reindeer in other circumpolar regions during the fall and winter (Finstad and Kielland, 2008; Aagnes *et al.*, 1995).

The main reason for assessing the mineral status of ruminants is to identify nutrient deficiencies and/or evaluate the efficacy of dietary supplementation. The most

critical component of any assessment is establishing the boundaries of what is normal in a productive animal. Whereas ranking criteria for mineral status in many domestic livestock have been established they have not been developed for domestic reindeer in the U.S. Although it is likely most free ranging reindeer populations on expansive rangelands meet all of their mineral requirements, reindeer grazed in sites with limited access to forage (snowcover), or fed a milled ration may have inadequate or unbalanced mineral intake. Blood parameters are frequently used in mineral status assessments because they are less invasive to sample than tissue and are correlated with the nutritional status of the animal. However, there are several limitations to using blood parameters to estimate mineral status: red blood cells have a life span of 30 to 60 days so concentrations of some trace minerals change slowly and homeostatic control mechanisms can limit changes in concentrations of some trace minerals in serum until tissue reserves are depleted (Miller, 1975). Also, careful handling of blood samples is needed to prevent hemolysis and contamination of serum by red blood cell contents, particularly by Zn, Cu and Fe. Reindeer handlings usually occur in remote locations that require travel by boat or snowmachine. All samples collected in this study were handled as one batch so if substantial hemolysis and contamination occurred because of transportation and handling there should have been a consistent shift of all Zn, Cu, and Fe values by batch. This did not occur (Table 3.3) suggesting there were little hemolysis effects on serum values. It is best to separate serum from the white/red blood cell clot within 2 hours of collection. If the serum sets on the clot for long periods of time, minerals that have higher intracellular content than serum can leach into the serum and artificially inflate results which

commonly occurs with Zn. Some samples collected in this study were not processed until 18 hours after collection so there was the possibility of Zn leaching into serum. However, the highest serum Zn values occurred in samples collected at near sites which were processed much more quickly (Davis, Gray, Olanna summer) than samples collected at locations that required extensive logistics and time to transport (winter, Noyakuk and Weyiuoanna). Additionally, almost all serum Zn values were below what is considered normal for livestock. There were also significant differences between male and female animals in the same herd. Severe mineral leaching would likely have masked any differences due to sex.

Blood samples collected in this study indicate little variation in serum mineral concentrations among individuals within a herd, but did show significant serum mineral differences across ranges (Table 3.3) suggesting broad scale differences in the characteristics of the forage base and in turn, the intake of nutrients of reindeer across the Seward Peninsula.

Reindeer have reduced metabolic needs for minerals during winter (McEwan and Whitehead, 1970), but because of the low nutritive value of lichen, free-ranging reindeer on some winter pastures have been reported to have low plasma concentrations of Ca that were likely influenced by a concurrent Mg deficiency (Ropstad *et al.*, 1997) or poor grazing conditions (Hyvärinen *et al.*, 1976). However, in this study Ca serum concentrations were negatively correlated with Mg concentrations and positively correlated with P in female yearlings during summer (Table 3.6). These serum data correspond to the concentrations of macrominerals found in sedge and willow species

most commonly eaten by reindeer during summer (Figures 3.3 and 3.4). Levels of serum Ca in Seward Peninsula reindeer were all found to be in the normal range for ruminant animals (NRC, 1996; Bjarghov *et al.*, 1976) except for males in summer on the Weyiuanna range (83.67 ± 5.81), which may be considered moderately deficient in cattle (NRC, 1996). However, Ropstad *et al.* (1997) determined that plasma levels of Ca in yearlings were lower than in adult animals so these values may not indicate a deficiency in yearlings sampled in this herd. No symptoms indicating Ca deficiency were reported for reindeer in this herd and relatively high calf weights and cow/calf ratios suggest adequate Ca nutrition to support good milk production among lactating females. Lactating beef cows and sheep require 0.27 to 0.58% Ca in the diet (NRC, 1996; NRC, 1985) and the concentration of Ca in sedges and particularly willows, forages commonly found in the June diets of Seward Peninsula reindeer, meet these requirements (Figs. 3.3 and 3.4).

Concentrations of Ca were negatively correlated to cow:calf ratios (Table 3.5). Yearling females were not included in the determination of the cow:calf ratio since two year olds were used as the reproductive cutoff age. In some herds on the Seward Peninsula female calves go into estrus, breed and lactate as yearlings (Prichard *et al.*, 1999, Table 3.4). If yearlings had given birth and were lactating, the proportion of calves per females in the herd would be inflated. Yearling females that were lactating would likely use Ca and have depressed serum Ca levels as Ropstad *et al.* (1997) found significant lower Ca levels in pregnant vs. barren females. Although lactation status of female yearlings was not determined in this study, including yearlings that were lactating

in the sampling both in the summer and winter (as long yearlings) could account for the negative correlation between concentrations of Ca and cow:calf ratios. There were significant differences in serum Ca due to sex in some herds (Table 3.3) suggesting males and females were mobilizing Ca to meet different physiological functions such as lactation in females and antler growth in males.

Inadequate phosphorus is the most prevalent mineral deficiency among the world's livestock (McDowell, 1992). Phosphorus requirements for maintenance in cattle are 16 mg P/kg body weight but increase significantly during periods of rapid growth, 3.9 g P/100g protein gain, and during lactation, 0.95g P/kg milk produced (NRC, 1996). Phosphorus levels of Seward Peninsula forage appear more than adequate to meet daily nutritional requirements (Figs. 3.3 and 3.4). Most phosphorus concentrations of reindeer serum were above 4.5 mg/dL except for Gray yearlings during winter that could be approaching marginal levels (Table 3.3). Marginal lower levels are 4.0 mg/dL for cattle and 3.1 mg/dL for sheep (Underwood and Suttle, 1999). However, P concentrations are often correlated with Ca concentrations as they are in this study because increased inorganic P levels are connected to increased secretion in the parathyroids for the mobilization of bone calcium (Hyvärinen *et al.*, 1976). Herd productivity in the Gray herd is high (Table 3.4) suggesting winter diet quality is high and/or animals are entering winter in excellent nutritional condition. This high plane of nutrition would reduce the need to mobilize bone Ca and secondarily, P.

Reindeer forage plants on the Seward Peninsula contain high concentrations of K in spring and summer relative to the other macrominerals (data taken from Finstad and

Kielland, 2008), (Figs. 3.3 and 3.4), that could, depending upon composition of overall diet, initiate 'grass tetany' in reindeer during spring and early summer (Church, 1988). Large intakes of K reduce Mg absorption and stimulate insulin release which can cause hyperirratbility of the neuromuscular system, trembling or convulsions that has been termed 'grass tetany' (Church, 1988). Subclinical signs can be found in cattle when serum magnesium falls below 15 μg/mL, but observable symptoms of 'grass tetany' appear when serum values fall below 12 μg/mL (Underwood and Suttle, 1999). However, serum Mg concentrations in June in all herds were well above concentrations believed to cause 'grass tetany' in cattle (Table 3.3). Even if Mg absorption was inhibited by high levels of K in some forage plants, there appears to be high enough levels of Mg in consumed forage to maintain normal serum concentrations.

Dietary requirements for Na are 0.08 to 0.09% in lactating ewes and 0.06-0.10% for cattle but may be higher in high output, lactating cows (NRC, 1985; NRC, 1996). Sodium deficiency among reindeer is not likely on the Seward Peninsula because most reindeer ranges are on the coast or border brackish lakes (Figure 3.1). Reindeer are often located on sea ice during spring or along the seacoast during summer (Reindeer Research Program unpublished satellite telemetry data) where melting sea ice would be a good source of Na for preparturient or lactating reindeer. Also, many semi-aquatic and aquatic plants consumed by Seward Peninsula reindeer contain substantial concentrations of Na (Fig. 3.5). Na concentrations found in reindeer serum values (Table 3.3) were within suggested normal values for sheep and near upper marginal bands for cattle (Underwood

and Suttle, 1999), but likely represent values of reindeer with acceptable levels of Na in the diet.

Deficiencies and imbalances of trace minerals can influence animal condition, fertility, productivity and mortality and have been reported for *Cervidae*, moose (*Alces alces*), in Alaska (Franzmann *et al.*, 1975). Zinc and Cu were reported as the trace minerals likely to be deficient in livestock production (Swenson *et al.*, 1996). Copper is an essential component of a number of enzymes although recommended concentrations of Cu in feed for ruminants are generally low; 7-15 *u*g/g (NRC, 1996). However, *Cervidae* appear to be particularly sensitive to deficiency and exhibit a number of signs; anemia, reduced growth, pigmentation changes in hair, fragile bones and low reproduction characterized by delayed or depressed estrus and immune function (Underwood, 1981). Concentrations of Cu in forages commonly found in the early summer diets of reindeer on the Seward Peninsula are generally adequate with willows providing more Cu than sedges but concentrations in forages dropped below recommended NRC levels by mid July (Figures 3.5 and 3.6). However, forbs commonly found in the diets of Seward Peninsula reindeer, particularly *Equisetum spp.* contain levels of Cu considerably above those of other forages (Finstad and Kielland, 2008) and provide a good source of dietary Cu. Serum Cu concentrations are usually not a good indicator of copper status but levels near or below 0.5 μg/mL usually indicate a depletion of liver Cu (Underwood and Suttle, 1999). There were significant seasonal differences in serum Cu concentrations of Seward Peninsula reindeer with summer levels being higher than in winter. Winter diets of Seward Peninsula reindeer consisted primarily of lichen

which is deficient in Cu, and animals were likely mobilizing stores in the liver to maintain homeostatic levels. Serum Cu values of reindeer were within the normal range for sheep and cattle except for summer and winter values in the Weyiuoanna herd (0.5-0.66 μg/mL) which could be considered as marginal or deficient in these ruminants (Underwood and Suttle, 1999; Kincaid, 2000).

The liver is the main storage organ for Cu and reflects the general Cu levels in the diet and provides a useful index of present Cu status and the degree of depletion. In cattle, although it is variable among breeds, liver copper concentrations less than 25 μg/g DM are indicative of deficiency (Underwood and Suttle, 1999). Winter Cu concentrations in liver from Seward Peninsula reindeer were above recommended levels except in the Weyiuoanna herd where both liver and serum Cu concentrations suggested a dietary deficiency of Cu.

The absorption of copper is poor in adult ruminants and may react antagonistically with Zn, Fe, Mo and S through competition for binding with the carrier protein metallothionein in intestinal mucosal cells. (Mills, 1987). When Mo concentration in the diet is excessive it produces a conditioned deficiency by inhibiting uptake and utilization of Cu. In serum, Mo is bound to protein, removes Cu from liver and creates urinary Cu loss. The presence of a Mo-Cu complex in serum is manifested as normal or elevated even though liver Cu is being depleted (Church, 1988). In the case of the Weyiuoanna herd both serum and winter liver concentrations of Cu (Fig. 3.9; Table 3.4) were low which would suggest excess Mo in the June diet did not cause a conditioned deficiency. However, samples from summer liver were not collected to

verify this assumption. Large intakes of Zn reduce concentrations of Cu in plasma and liver of cattle and sheep (Kincaid, 2000). Many Seward Peninsula forage species have Zn concentrations considerably above recommended intake levels (NRC, 1996), (Fig. 3.8). For example, *Salix fuscescens,* a willow species commonly found in boggy habitats on the Seward Peninsula (Swanson *et al.*, 1985) and commonly eaten by reindeer, contain high concentrations of Zn (200 μg/g), compared to other forages (Fig. 3.8), which if consumed in substantial quantities could initiate a conditioned Cu deficiency. However, high intake of Zn in the diet should cause elevated serum Zn concentrations, but values in the Weyiuoanna herd did not indicate an excessive intake (Table 3.3). Nonetheless, high levels of other minerals such as sulfphur (S), iron (Fe) and cadmium (Cd) also inhibit the absorption of Cu which may have initiated a conditioned deficiency. Although the diet composition data suggests Cu intake in the Weyiuoanna herd should have met requirements, microhistological fecal analysis may not have accurately reflected the temporal and spatial diet of reindeer in this particular range. The Weyiuoanna range is unique in its makeup of ecological sites because it contains a high proportion of tussock tundra, but a relatively low proportion of sedges and grasses compared to other ranges (Fig. 3.2). Tussock tundra is dominated by *Eriophorum vaginatum*, a sedge whose leaves are not considered primary forage and are not usually consumed by Seward Peninsula reindeer (unpublished UAF-RRP data). The high proportion of tussock tundra and relative low proportion of sedge and grass dominated ecological sites may have limited the diversity of spring and summer diet of Weyiuoanna reindeer and limited the intake of dietary Cu.

Growth retardation and infertility is a common feature of copper deficiency in ruminants. However, Seward Peninsula data on reindeer productivity (Table 3.4) suggest the marginal or deficient serum and liver Cu levels found in the Weyiuoanna herd did not compromise production in the year of this study. Although, a deficiency in copper is often not manifested in the first year (Underwood and Suttle, 1999) and productivity in the Weyiuoanna herd may have been compromised if the apparent Cu deficiency continued for several years. Further investigation of Cu deficiency in Weyiuoanna reindeer has become difficult because a large proportion of the herd was lost to outmigration with caribou (Finstad *et al.*, 2006).

Concentrations of Zn in forages of Seward Peninsula reindeer were considerably above those recommended for cattle, 30 μg/g DM (NRC, 1996), (Figs. 3.5, 3.6 and 3.8). Serum values may be used to detect severe deficiencies but are of limited value when deficiencies are marginal. Serum Zn values found in reindeer herds across ranges (Table 3.3) were generally lower than those recommended for cattle and would be considered deficient to marginally deficient (Wegner *et al.*, 1973). However, reindeer serum values of this study were within the range of serum values found in domestic sheep (Yur *et al.*, 2002). Reindeer are often herded for considerable distance prior to handlings and the handlings themselves are physically and psychological stressful for free range reindeer. These stressors may have contributed to low serum Zn. Hyperthermal stress had a depressing effect on serum Zn on dairy cattle (Wegner *et al.*, 1973). Stress may also cause an overall decline in serum Fe with a corresponding rise in serum Cu (Underwood and Suttle, 1999). Correlation coefficients of serum Zn, Fe and Cu concentrations across

herds (Table 3.6) suggest stress may have influenced the concentration of these minerals in serum but the association was not significant. The relatively high concentration of Zn found in forages eaten by reindeer suggests the lower serum Zn concentrations, relative to cattle, may be normal in reindeer, however as pointed out previously, stress of herding and handling may have depressed concentrations. Concentrations of serum Zn demonstrated a positive, but nonsignificant, relationship to calf weight and calf: cow ratios in herds (Table 3.6).

Most reindeer forage plants on the Seward Peninsula contain substantial Fe (Finstad and Kielland, 2008) and a deficiency is unlikely. However, animals with severe parasitic infections or diseases that cause chronic blood loss may show signs of deficiency. Serum Fe was found to be generally higher in reindeer compared to cattle but this is consistent with higher Fe concentrations found in muscle tissue of reindeer than found in cattle (Rincker *et al.*, 2006).

Selenium requirement in diet of cattle is 0.02 -0.04 mg/kg (NRC, 1996); forage of the Seward Peninsula was found to have concentrations high enough to meet these requirements (Finstad and Kielland, 2008). Deficiencies can cause muscular degeneration and poor production in ruminants and possibly increase perinatal mortality and growth retardation of calves (Underwood and Suttle, 1999). Normal blood values for cattle range between 0.2-0.24 μg/mL but are higher for sheep (Underwood and Suttle, 1999). Selenium values in blood of reindeer across ranges were found to be slightly higher than normal for cattle and normal for sheep (Table 3.3). There was a negative correlation (R^2 = -0.74) to reindeer calf weight (Table 3.6).

In conclusion, I found that reindeer ranges across the Seward Peninsula varied considerably in the composition of ecological sites found within range boundaries. However, this variation in vegetation composition was not a reliable predictor of reindeer diet composition. Reindeer appear to be very selective, both temporally and spatially in what they eat, but it is at a scale finer than expressed by an ecological site. Reindeer herders must characterize and identify high quality grazing areas based on the occurrence of preferred forage plants within an area instead of ecological site classification per se. Willows, sedges and lichen are the forages most selected by reindeer because these plants provide the most digestible protein and energy (Finstad and Kielland, 2008) during a time period when reindeer are lactating and depositing hard and soft tissue.

Serum and tissue values of reindeer varied significantly by sex, season and across ranges, reflecting both differences in diet and physiological state. For the most part, serum and tissue values fell within the expected normal values for ruminants with the exception of one herd. Establishing mineral concentrations in tissues of animals that exhibit good growth and reproduction will set standards to identify potential nutritional problems in populations whose tissue values fall outside normal values. Reindeer on the Seward Peninsula exhibit high body weights and growth rates when compared to other circumpolar reindeer populations (Finstad and Prichard, 1999); and calf production of all herds was good during the time serum and tissue samples were collected for this study. Although one can not be sure without controlled experiments, the serum and tissue mineral values found in this study provides a baseline for comparison if grazing

conditions change on the Seward Peninsula and may be used as a baseline for other *Rangifer* herds.

Currently, the vegetation of the Seward Peninsula provides a diversity of forage that result in excellent nutritional status and productivity of reindeer across most ranges. Intense grazing or other environmental factors such as climate change may restructure vegetation communities and modify the ecological site composition of reindeer ranges in the future. We may use the results of this study to monitor the direction of these landscape changes on diet, nutritional status and productivity of reindeer. This will give us a better understanding of the interactions among landscape factors, foraging ecology and productivity of reindeer on the Seward Peninsula and provide land managers and producers the ability to respond to change in an appropriate and sustainable manner.

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Figures

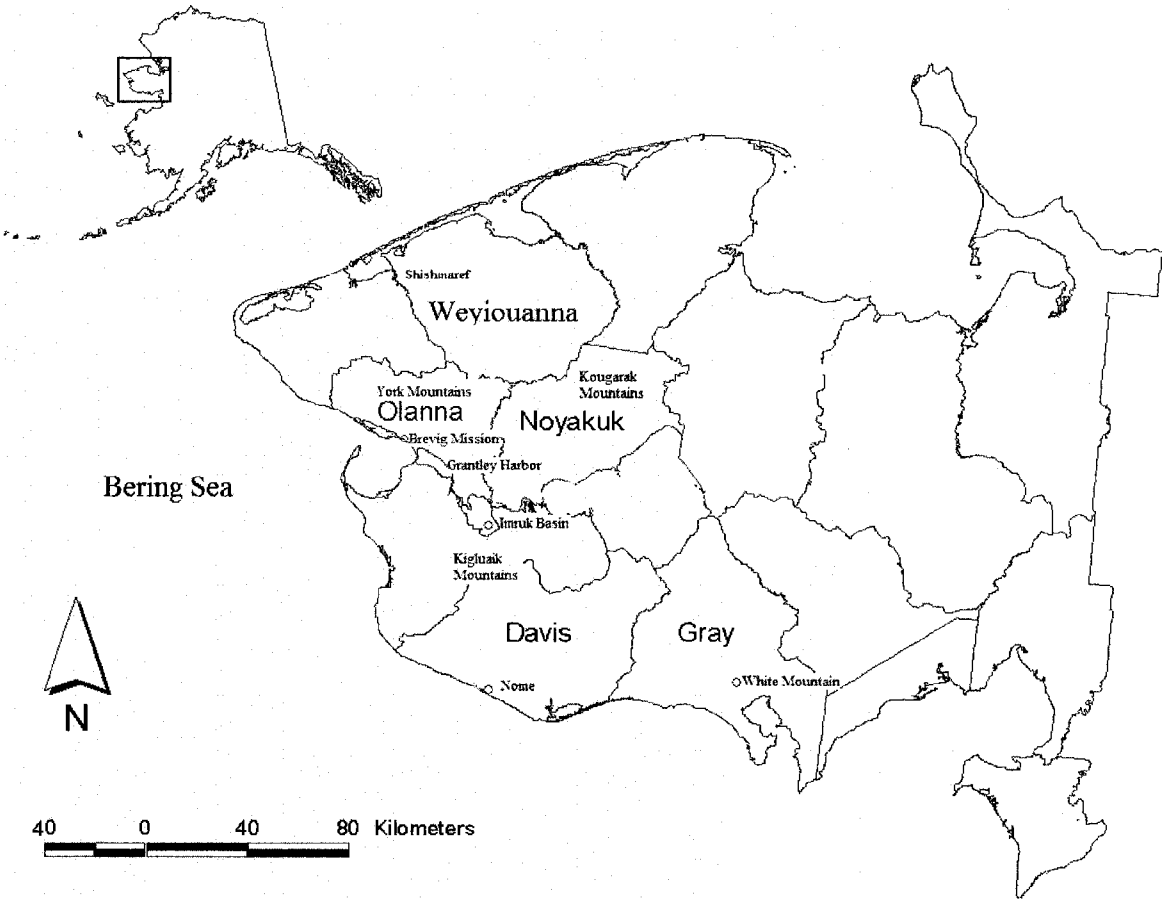

Figure 3.1 Map of the prominent features and reindeer range allotments of the Seward Peninsula, Alaska included in this study.

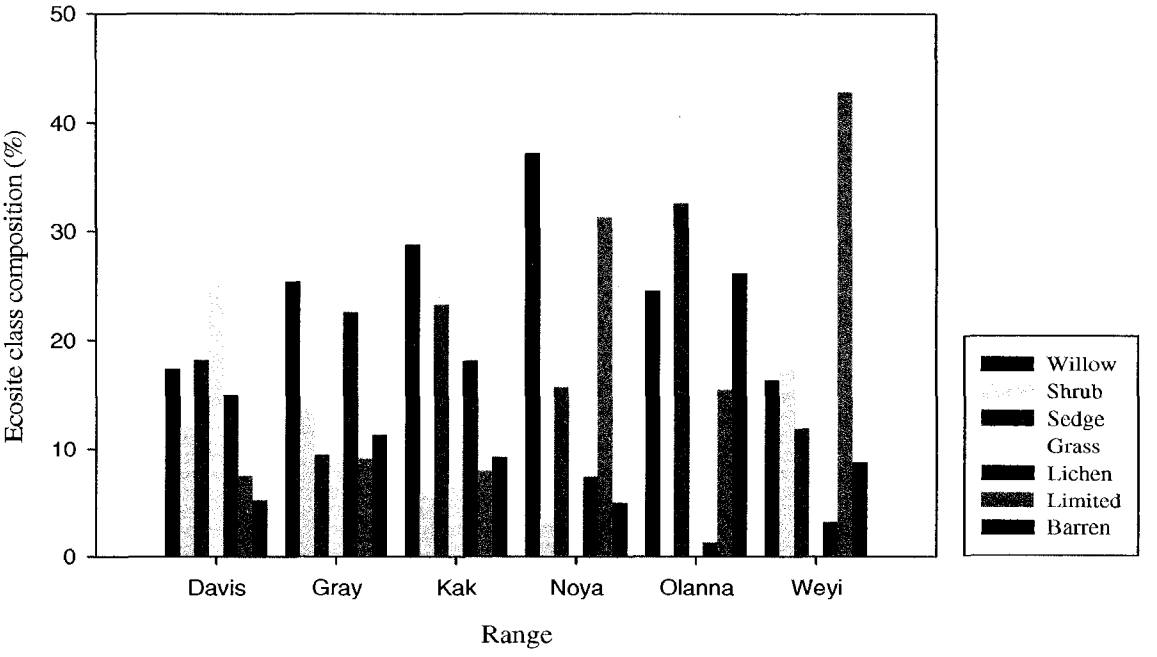

Figure 3.2 Percentage of ecological site class for range allotments on the Seward Peninsula, Alaska

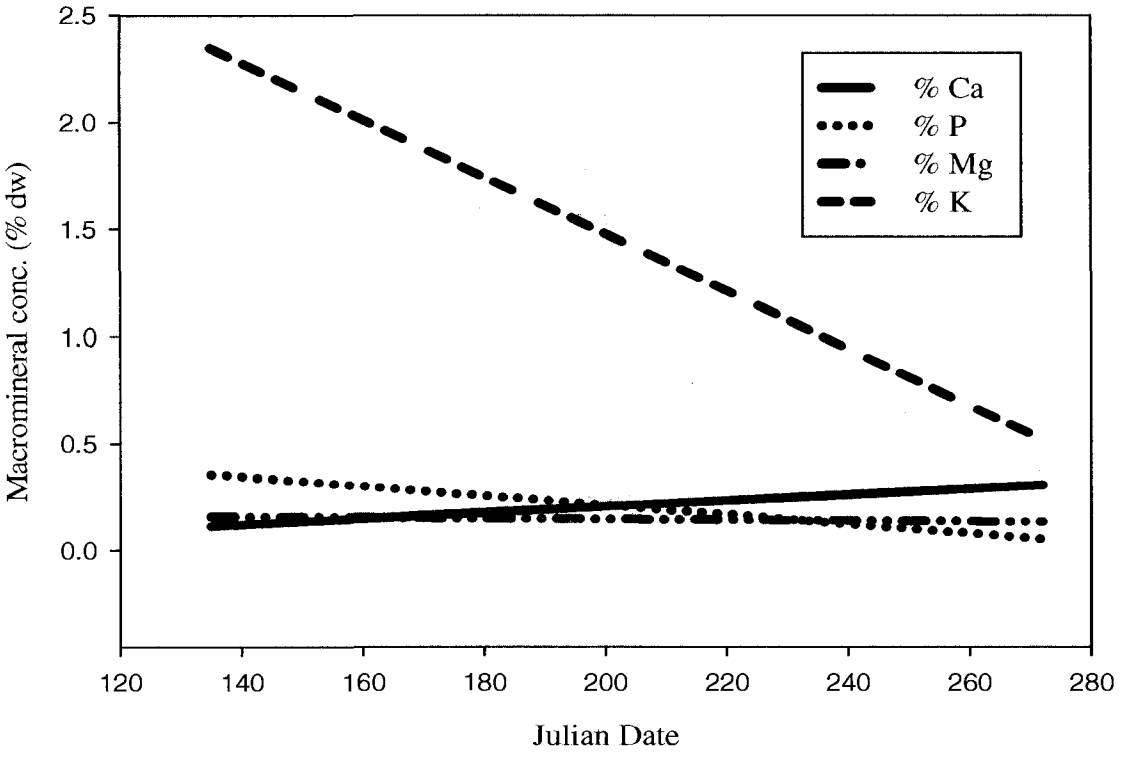

Figure 3.3 Seasonal macromineral concentrations of sedges commonly found in diets of Seward Peninsula reindeer.
Carex aquatilus, Carex bigelowii, Eriophorum angustifolium, and *Carex lyngbaei* (n = 351).
% Ca = - 0.08 + 0.0014(JDate), $p < 0.001$, $R^2 = 0.11$;
% P = 0.65 - 0.002(JDate), $p < 0.001$, $R^2 = 0.40$.
% Mg = 0.18 - 0.0002(JDate), $p = 0.008$, $R^2 = 0.20$;
% K = 4.15 – 0.013(JDate), $p < 0.001$, $R^2 = 0.27$

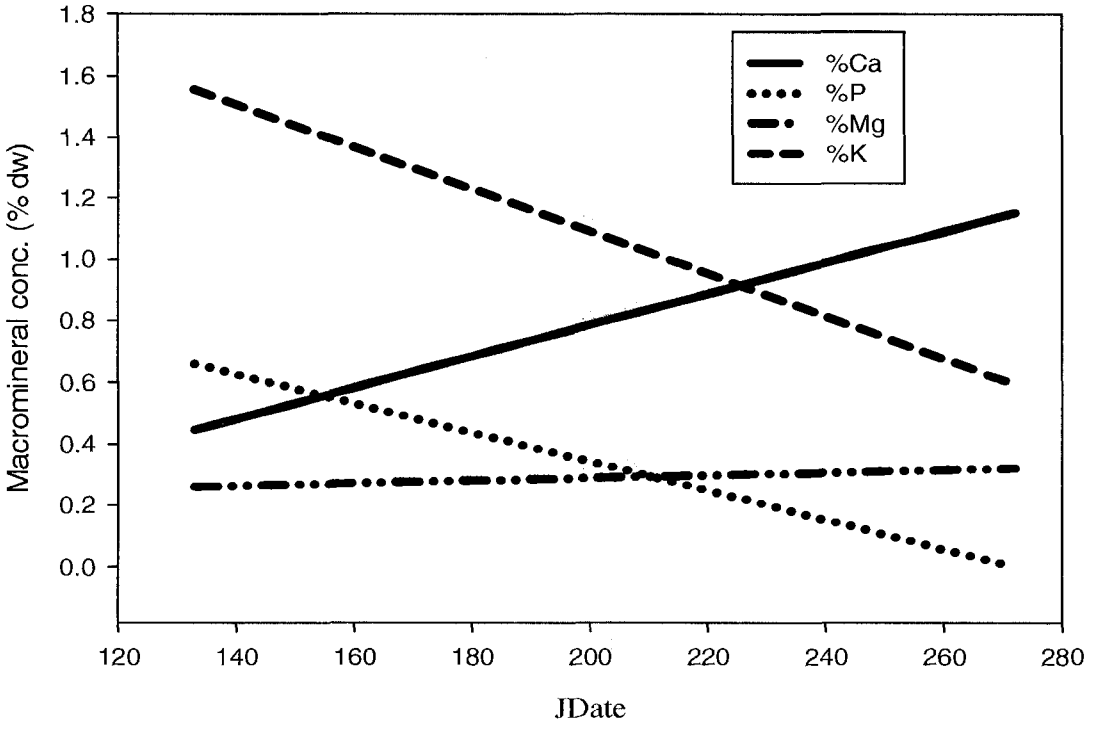

Figure 3.4 Seasonal concentrations of macrominerals in willows commonly found in diets of Seward Peninsula reindeer.
Salix pulchra, lanata, alexensis, and *fuscescens* (n = 341).
% Ca = -0.23 + 0.005(JDate), $p < 0.001$, $R^2 = 0.15$.
% P = 1.31 - 0.005(JDate), $p < 0.001$, $R^2 = 0.55$.
% Mg = 0.2 + 0.0004(JDate), $p < 0.001$, $R^2 = 0.55$.
% K = 2.45 – 0.007(JDate), $p < 0.001$, $R^2 = 0.35$.

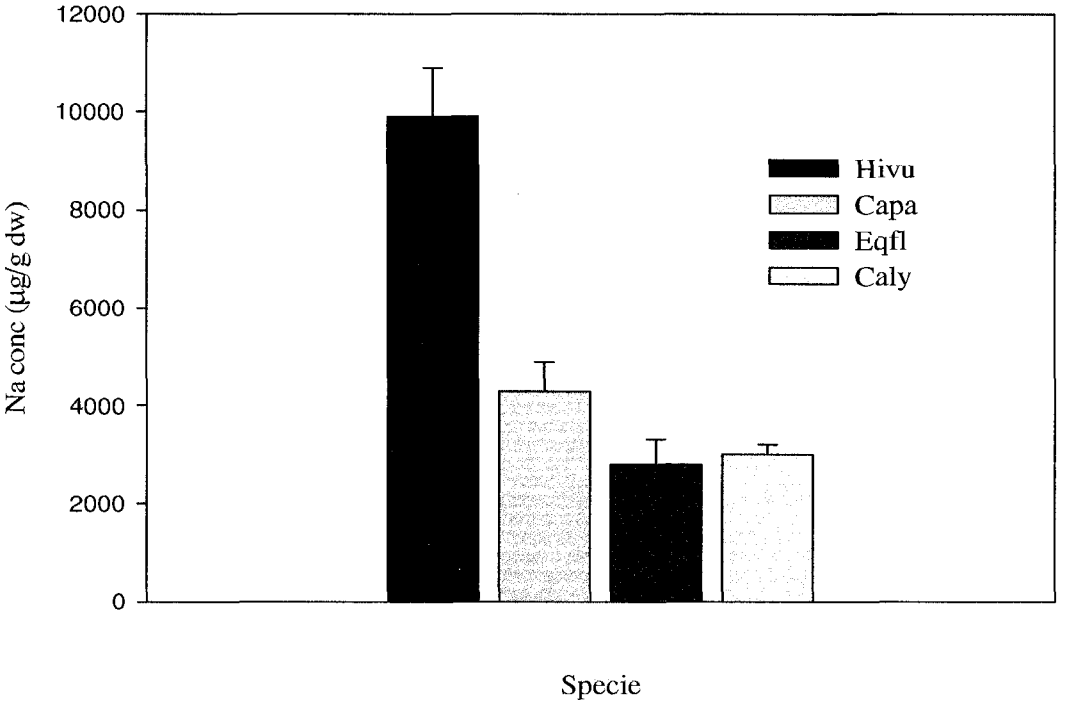

Figure 3.5 Na concentration (N = 39) of aquatic and semi aquatic plants commonly found in diets of Seward Peninsula reindeer. *Hivu = Hippuris vilgiris*, *Capa = Caltha palustris*, *Eqfl = Equisetum fluviatile*, *Caly = Carex lyngbaeii*. Mean (±SE).

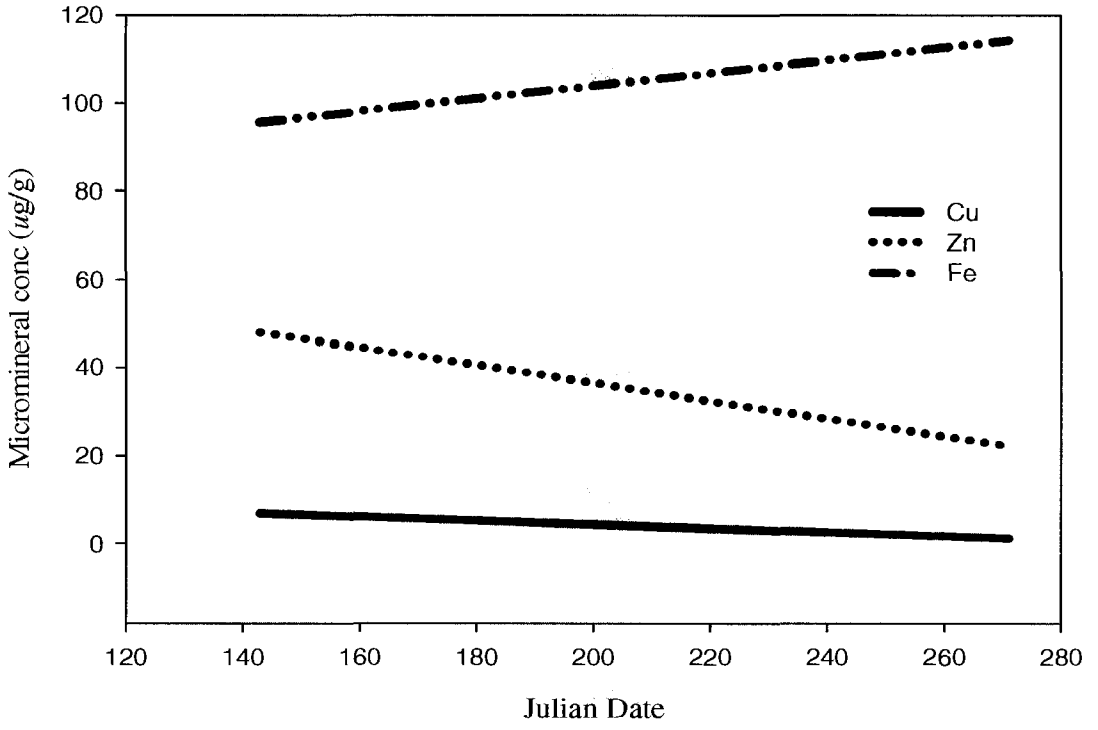

Figure 3.6 Seasonal concentrations of microminerals in sedges commonly found in diets of Seward Peninsula reindeer. *Carex aquatilus, Carex bigelowii, Eriophorum angustifolium,* and *Carex lyngbaei* (N = 353).
µg/g Cu = 13.4 - 0.04(JDate), $p < 0.001$, $R^2 = 0.15$.
µg/g Zn = 77.0 - 0.2(JDate), $p < 0.001$, $R^2 = 0.20$.
µg/g Fe = 75.0 + 0.14(JDate), $p = 0.16$, $R^2 = 0.05$.

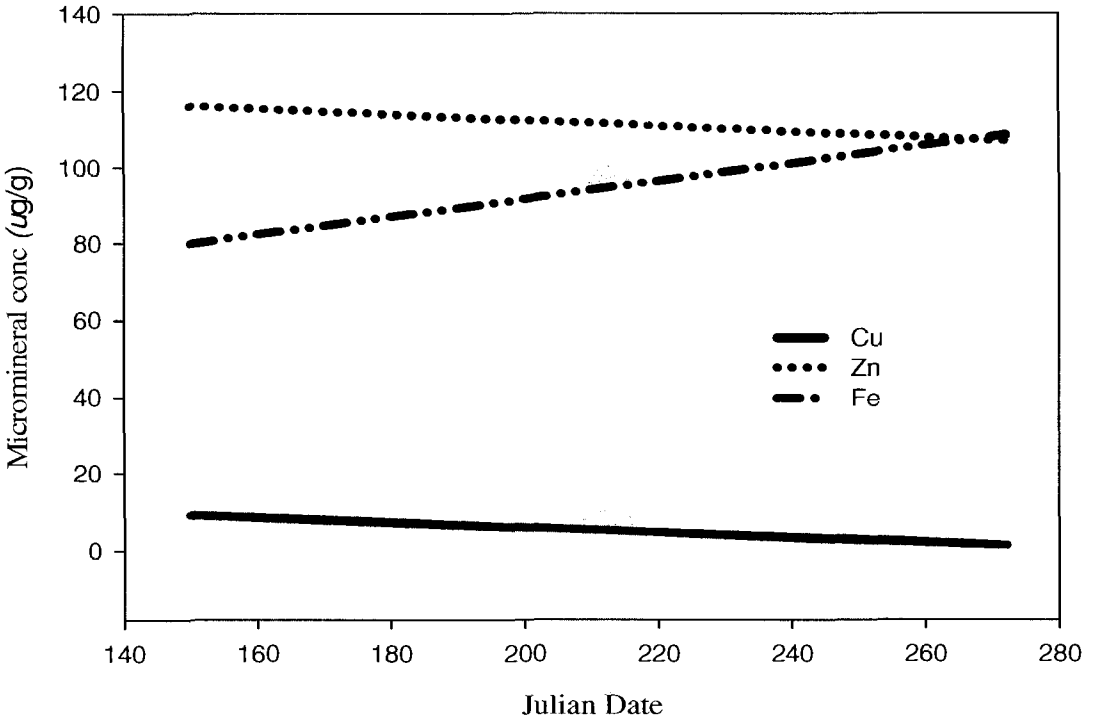

Figure 3.7 Seasonal concentrations of microminerals in willows commonly found in diets of Seward Peninsula reindeer. *Salix pulchra, lanata,* and *alaxensis,* (N =270).
μg/g Cu = 18.2 - 0.06(JDate), $p < 00.01$, $R^2 = 0.50$;
μg/g Zn = 131.1 - 0.1(JDate), $p = 0.27$, $R^2 = 0.05$.
μg/g Fe = 44.0 + 0.24(JDate), $p = 0.003$, $R^2 = 0.30$.

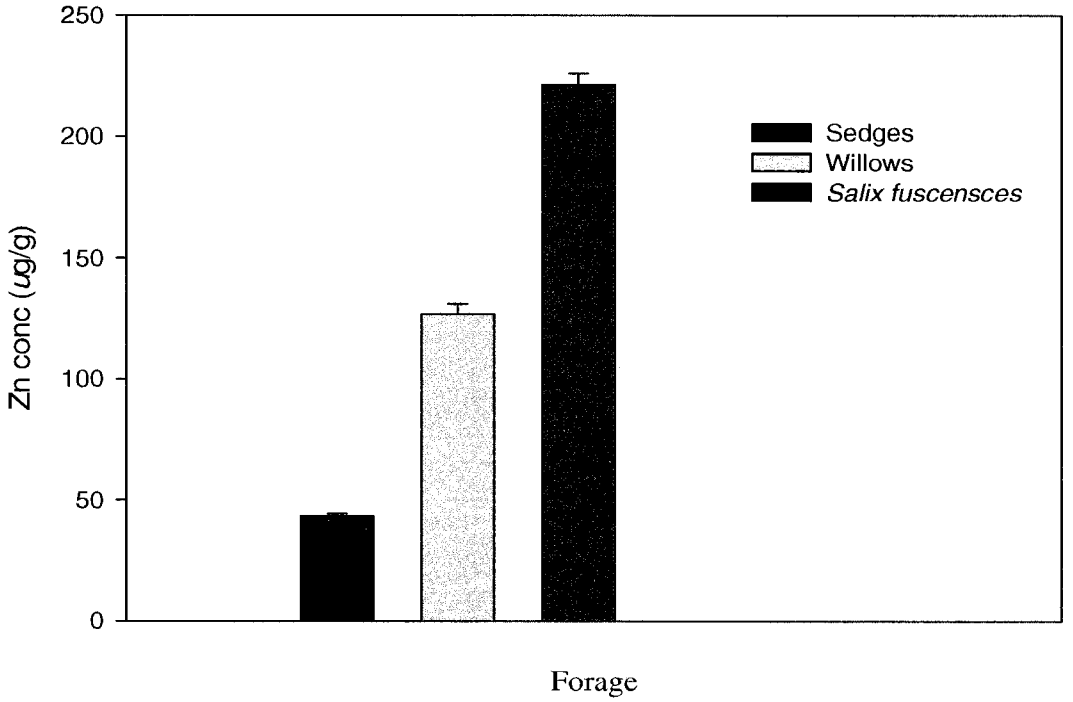

Figure 3.8 Concentration of Zn (μg/g) in forages commonly found in the diets of Seward Peninsula reindeer. Mean (± SE). Data taken from Finstad and Kielland, 2007.

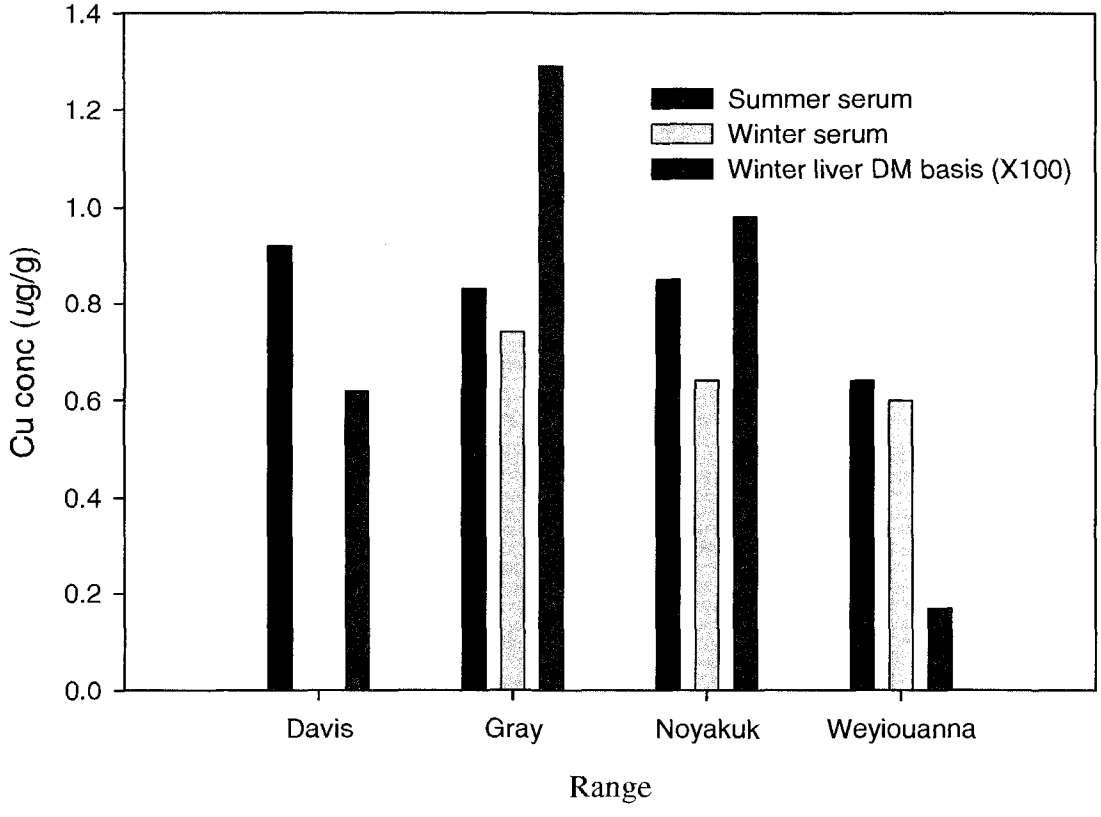

Figure 3.9 Concentration of Cu (μg/g) in serum and liver of Seward Peninsula reindeer. (Mean ± S.E.). Liver n = 37, 30, 26, 8

Tables

Table 3.1 Percentage (%) of ecological sites found in range allotments on the Seward Peninsula, Alaska.

Ecological Site	Davis	Gray	Kakarak	Noyakuk	Olanna	Weyiouanna	Class
Alpine Mountain Meadow (43)	25.5	8.8	6.8				Grass
Bald Limestone Slope (72)	3.2		1.8	5.0	24.4	8.8	Barren
Dryas Limestone Slope (71)	3.7	2.8		3.3	2.6	0.8	Limited
Barren (81)	2.1		7.5		1.8		Barren
Lichen Granitic Slope (Alpine) (70)	5.9	6.2	13.9	1.4	1.2		Limited
Lichen Meadow (Mountain) (61)	6.4	6.5		6.0		3.1	Limited
Lichen-Sedge (63)	2.6	5.1	2.0				Limited
Lichen (Tussock Tundra) (60)		4.9	2.2				Limited
Tussock Tundra (42)	3.8	2.8	7.9	28.0	12.9	41.9	Limited
Tussock Tundra, Sedge (42A)	4.4	1.7	1.5		5.0		Sedge
Sedge (Wet Meadow) (52)	9.4	4.3	17.5	15.7	27.6		Sedge
Sedge (Drainageway) (54)	4.4		4.2			7.8	Sedge
Marsh (Tidal) (51)		3.4				2.4	Sedge
Breached Lake Bed (56)						1.6	Sedge
Low Shrub (Floodplain) (34)	4.5	2.2	8.0	3.6		1.4	Willow
Low Shrub (Hillside) (35)	9.2	7.2		2.1			Shrub
Shrub Meadow (Mountain) (41)	6.5	14.8	12.5	20.4	16.3	11.4	Willow
Shrub-Willow (Hillside) (35B)						2.6	Willow
Tall Shrub (Drainageway) (21)	3.6	2.8	4.4	13.3	4.9		Willow
Tall Shrub (Floodplain) (20)	2.8	2.8	3.8				Willow
Tall Shrub (Hillside) (22)	2.0	6.4	4.0			13.9	Shrub
Mixed Shrub (Tundra) (32)			1.7	1.3		3.3	Shrub
Mixed Forest (Floodplain) (10)		3.5					Limited
White Spruce (Upland) (12)		11.3					B
Riverwash (82)		2.8			3.4	0.9	W

Table 3.2 Percentage of plant growth forms found in seasonal diets of Seward Peninsula reindeer determined by microhistological analysis of pooled fecal samples. Comparison of seasonal column means across ranges * $p < 0.05$; ** $p < 0.01$; n.s. = not significant.

		Salix	Shrubs	Grass	Sedge	Equi	Forbs	Lichen	Mosses	Rhizome
Davis	Spring	4.1 ± 0.6	10.2 ± 1.3	4.4 ± 0.9	9.5 ± 0.9	3.5 ± 0.1	1.6 ± 0.4	56.2 ± 2.1	10.4 ± 1.1	0.3 ± 0.2
	n / p	36 / n.s	36 / **	36 / n.s.	36 / n.s.	36 / **	36 / n.s	36 / *	36 / n.s.	36 / n.s.
	June	19.5 ± 3.0	3.7 ± 1.0	4.2 ± 0.8	9.6 ± 1.4	6.7 ± 1.9	2.7 ± 1.0	49.0 ± 3.2	4.4 ± 0.7	0
	n / p	21 / *	21 / n.s	21 / n.s	21 / **	21 / *	21 / n.s	21 / *	21 / **	21 / n.s.
	July	12.5 ± 1.9	2.4 ± 0.6	2.3 ± 0.8	11.8 ± 1.9	3.2 ± 1.0	3.4 ± 0.6	62.3 ± 3.4	2.1 ± 0.4	0
	n / p	23 / n.s.	23 / n.s.	23 / n.s.	23 / **	23 / *	23 / n.s	23 / **	23 / **	23 / n.s
	Fall	3.8 ± 1.4	2.7 ± 0.9	1.2 ± 0.5	6.7 ± 4.7	0.00	1.7 ± 0.6	81.3 ± 3.5	2.7 ± 1.5	0
	n / p	6 / n.s	6 / n.s	6 / n.s	6 / n.s	6 / *	6 / n.s.	6 / *	6 / n.s	6 / n.s
	Winter	4.0 ± 1.5	2.3 ± 0.7	4.6 ± 1.4	10.7 ± 1.1	1.2 ± 0.7	0.9 ± 0.09	71.8 ± 3.0	5.4 ± 1.9	0
	n / p	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / **	4 / n.s	4 / n.s	4 / n.s
Gray	Spring	2.4 ± 0.7	2.6 ± 0.7	2.5 ± 0.6	8.6 ± 1.4	4.3 ± 2.2	2.4 ± 2.0	65.1 ± 2.3	8.6 ± 1.3	3.5 ± 1.6
	n / p	29 / n.s	29 / **	29 / n.s.	29 / n.s.	29 / **	29 / n.s	29 / *	29 / n.s.	29 / n.s.
	June	26.6 ± 3.2	1.7 ± 1.1	7.3 ± 1.6	25.1 ± 3.0	0.9± 0.4	0.8 ± 0.9	36.8 ± 5.5	0.6 ± 0.2	0.2 ± 0.1
	n / p	23 / *	23 / n.s	23 / n.s	23 / **	23 / *	23 / n.s	23 / *	23 / **	23 / n.s.
	July	30.5 ± 4.8	1.2 ± 0.8	8.5 ± 1.9	31.8 ± 3.9	1.2 ± 0.7	1.8 ± 0.9	24.1 ± 7.2	0.6 ± 0.9	0.3 ± 0.3
	n / p	15 / n.s.	15 / n.s.	15 / n.s.	15 / **	15 / *	15 / n.s	15 / **	15 / **	15 / n.s
	Fall	1.4 ± 0.7	3.9 ± 0.8	4.3 ± 0.4	8.1 ± 1.4	5.7 ± 1.4	2.3 ± 1.1	68.7 ± 2.3	3.6 ± 0.5	1.0 ± 0.3
	n / p	24 / n.s	24 / n.s	24 / n.s	24 / n.s	24 / *	24 / n.s.	24 / *	24 / n.s	24 / n.s
	Winter	0.8 ± 0.3	3.8 ± 0.9	2.9 ± 1.0	9.6 ± 1.9	0.2 ± 0.1	0.16 ± 0.3	71.9 ± 3.6	9.4 ± 2.3	1.3 ± 0.8
	n / p	18 / n.s	18 / n.s	18 / n.s	18 / n.s	18 / n.s	18 / **	18 / n.s	18 / n.s	18 / n.s

Table 3.2 continued

		Salix	Shrubs	Grass	Sedge	Equi	Forbs	Lichen	Mosses	Rhizome
Kakarak	June	35.7 ± 2.6	1.6 ± 0.7	1.8 ± 0.7	19.9 ± 5.9	2.5 ± 1.4	3.4 ± 1.6	30.6 ± 3.0	4.5 ± 1.9	0
	n / p	4 / *	4 / n.s	4 / n.s	4 / **	4 / *	4 / n.s	4 / *	4 / **	4 / n.s.
Noyakuk	Spring	2.4 ± 0.5	5.5 ± 1.2	2.5 ± 1.4	7.8 ± 2.7	4.4 ± 1.9	1.3 ± 0.7	68.8 ± 4.4	7.3 ± 2.0	0
	n / p	7 / n.s	7 / *	7 / n.s.	7 / n.s.	7 / **	7 / n.s	7 / *	7 / n.s.	7 / n.s.
	June	41.4 ± 9.6	4.7 ± 4.7	2.6 ± 0.6	7.8 ± 3.8	0	1.2 ± 1.2	38.9 ± 14.4	3.4 ± 3.4	0
	n / p	2 / *	2 / n.s	2 / n.s	2 / **	2 / *	2 / n.s	2 / *	2 / **	2 / n.s.
	Winter	5.4 ± 1.6	7.3 ± 0.9	1.2 ± 0.6	3.6 ± 2.2	0	2.8 ± 1.0	76.6 ± 3.1	3.1 ± 0.7	0
	n / p	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / **	4 / n.s	4 / n.s	4 / n.s
Olanna	Spring	4.2 ± 1.2	1.9 ± 0.6	3.3 ± 0.7	8.8 ± 1.6	14.2 ± 5.1	1.0 ± 0.5	56.0 ± 5.1	8.2 ± 1.6	2.5 ± 1.0
	n / p	9 / n.s	9 / *	9 / n.s.	9 / n.s.	9 / **	9 / n.s	9 / *	9 / n.s.	9 / n.s.
	June	13.9 ± 3.1	1.6 ± 0.8	6.3 ± 2.2	11.6 ± 2.1	8.5 ± 2.3	0.6 ± 0.3	49.4 ± 3.2	4.8 ± 0.6	3.3 ± 2.6
	n / p	9 / *	9 / n.s	9 / n.s	9 / **	9 / *	9 / n.s	9 / *	9 / **	9 / n.s.
	July	17.0 ± 2.7	3.9 ± 2.2	1.4 ± 0.6	12.1 ± 3.9	7.2 ± 1.8	3.0 ± 1.0	48.8 ± 5.0	5.9 ± 1.2	0.8 ± 0.6
	n / p	9 / n.s.	9 / n.s.	9 / n.s.	9 / **	9 / *	9 / n.s	9 / **	9 / **	9 / n.s
	Winter	0	7.7	0.6	2.5	0	0	76	13.3	0
	n / p	1 / n.s	1 / n.s	1 / n.s	1 / n.s	1 / n.s	1 / **	1 / n.s	1 / n.s	1 / n.s
Weyiouanna	June	40.1 ± 3.4	2.7 ± 0.9	4.7 ± 0.9	12.0 ± 3.3	4.4 ± 1.4	2.3 ± 1.3	31.4 ± 4.5	1.8 ± 0.5	0
	n / p	9 / *	9 / n.s	9 / n.s.	9 / **	9 / *	9 / n.s.	9 / *	9 / **	9 / n.s.

Table 3.3 Serum mineral means (± standard error) found in yearling male (M) and female (F) reindeer across ranges of the Seward Peninsula, Alaska. †Comparison of column means across ranges,* $p \leq 0.05$. ††Comparison of sex and season column means within range, * $p \leq 0.05$.

Range	Season	Sex	Zn μg/mL	P μg/mL	Fe μg/mL	Mg μg/mL	Cu μg/mL	Ca μg/mL	Na mEq/L	Se μg/mL
Davis	S	F	0.74 ± 0.10	70.85 ± 4.44	1.35 ± 0.18	26.62 ± 0.9	0.98 ± 0.06	102.00 ±.2.47	151.38 ± 1.54	0.25 ± 0.02
Davis	S	M	0.75 ± 0.10	64.08 ± 3.79	2.08 ± 0.24	25.93 ± 0.65	0.86 ± 0.04	101.42 ± 1.60	152.92 ± 0.92	0.21 ± 0.03
†			* /	* /	/ *	* /	* /	* /	* /	* /
Gray	S	F	0.86 ± 0.06	69.04 ± 3.31	1.62 ± 0.10	27.08 ± 0.47	0.83 ± 0.04	97.16 ± 2.17	149.48 ± 2.32	0.15 ± 0.01
Gray	S	M	0.89 ± 0.07	66.95 ± 2.87	1.64 ± 0.12	25.47 ± 0.47	0.83 ± 0.05	105.21 ± 1.00	154.74 ± 1.22	0.15 ± 0.01
††			* / * /	* / * /	/ /	* / * / *	* / /	* / / *	* / * /	* / * /
Gray	W	F	0.59 ± 0.02	36.00 ± 2.62	1.98 ± 0.18	22.33 ± 0.49	0.63 ± 0.07	106.67 ± 3.33	137.00 ± 2.78	0.30 ± 0.01
Gray	W	M	0.56 ± 0.03	50.43 ± 3.17	1.40 ± 0.14	21.14 ± 0.26	0.83 ± 0.08	92.71 ± 1.02	134.33 ± 2.75	0.25 ± 0.01
††			* / * /	* / * / *	/ / *	/ * / *	/ / *	* / / *	* / * /	* / * / *
Kakarak	S	F	0.62 ± 0.04	62.40 ± 8.15	1.78 ± 0.15	23.60 ± 0.68	0.77 ± 0.07	93.20 ± 1.96	149.00 ± 2.53	
Kakarak	S	M	0.53 ± 0.03	59.29 ± 4.17	1.81 ± 0.26	23.29 ± 0.61	0.76 ± 0.07	93.29 ± 3.22	147.71 ± 0.97	
†			* /	* /	/	* /	* /	* /	* /	
Noyakuk	S	F	0.78 ± 0.05	79.06 ± 2.92	1.63 ± 0.17	24.12 ± 0.45	0.84 ± 0.05	101.81 ± 1.19	148.56 ± 1.47	
Noyakuk	S	M	0.73 ± 0.05	88.68 ± 2.83	1.43 ± 0.14	24.68 ± 0.34	0.86 ± 0.05	101.63 ± 1.34	147.58 ± 1.54	
††			* / /	* / * / *	/ /	* / /	* / * /	* / /	* / /	
Noyakuk	W	F	0.61 ± 0.04	52.40 ± 2.89	1.64 ± 0.31	24.80 ± 0.97	0.63 ± 0.04	103.00 ± 3.02		0.14 ± 0.02
Noyakuk	W	M	0.60	37.00	1.40	23.00	0.66	102.00		0.17
††			* / /	* / * /	/ /	/ /	/ * /	* / /		* / /
Olanna	S	F	0.65 ± 0.02	78.94 ± 2.63	1.88 ± 0.15	24.39 ± 0.54	0.75 ± 0.05	109.72 ± 1.73	147.53 ± 1.6	0.11 ± 0.01
Olanna	S	M	0.72 ± 0.03	84.50 ± 5.42	2.04 ± 0.10	23.50 ± 0.65	0.67 ± 0.02	111.20 ± 2.31	148.50 ± 1.26	0.08 ± 0.05
††			* / * / *	* / * /	/ * /	* / * /	* / /	* / * /	* / /	* / * /
Olanna	W	F	0.64 ± 0.02	57.00 ± 4.55	1.68 ± 0.11	22.71 ± 0.81	0.67 ± 0.03	98.07 ± 1.47	148.20 ± 2.21	0.21 ± 0.02
Olanna	W	M	0.62 ± 0.02	53.50 ± 4.26	1.49 ± 0.10	22.71 ± 0.74	0.67 ± 0.05	97.86 ± 1.74	147.33 ± 1.74	0.23 ± 0.01
††			* / * /	* / * /	/ * /	/ * /	/ /	* / * /	* / /	* / * /
Weyiouanna	S	F	0.61 ± 0.03	77.59 ± 2.20	1.62 ± 0.12	24.59 ± 0.45	0.66 ± 0.03	99.12 ± 1.72	150.65 ± 0.72	0.12 ± 0.01
Weyiouanna	S	M	0.36 ± 0.05	61.00 ± 5.77	0.80 ± 0.12	18.67 ± 1.20	0.50 ± 0.14	83.67 ± 5.81	144.00 ± 3.21	0.11 ± 0.01
††			* / / *	* / * / *	/ / *	* / * / *	* / /	* / / *	* / * / *	* / * /
Weyiouanna	W	F	0.53 ± 0.03	55.20 ± 6.44	1.67 ± 0.11	20.20 ± 1.26	0.62 ± 0.05	91.20 ± 3.56	142.20 ± 4.22	0.19 ± 0.01
Weyiouanna	W	M	0.55 ± 0.02	65.33 ± 4.74	1.59 ± 0.17	23.17 ± 0.54	0.56 ± 0.05	95.67 ± 1.56	136.00 ± 2.00	0.22 ± 0.02
††			* / /	* / * /	/ /	/ * /	/ /	* / /	* / * /	* / * /

Table 3.4 Calf weights standardized to June 25th date for reindeer herds across the Seward Peninsula. Calf /cow ratio was estimated using total number of calves and adult females (over two years of age) seen during June handlings.

	Davis			Gray			Noyakuk			Olanna			Weyiouanna		
	Female	Male	Mean	Female	Male	Mean	Female	Male	Mean	Female	Male	Mean	Female	Male	Mean
June 25th calf weight (kg)	26.4	28.3	27.5	32.9	35.2	34.0	31.0	33.0	32.4	29.9	32.5	31.4	30.9	32.9	31.4
SEM	±0.1	± 0.1	± 0.1	± 0.3	± 0.4	± 0.2	± 0.5	± 0.5	± 0.3	± 0.4	± 0.4	± 0.3	± 0.3	± 0.4	± 0.3
Calf/cow ratio (2 yr. old or older)		59.7			80.7			116.1†			55.1			76.1	

† 55% of yearling females in this herd were lactating, assumed to have calf which contributed to total

Table 3.5 Pearson correlation matrix of percentage of plant growth form found in fecal samples of reindeer from the six ranges on the Seward Peninsula included in this study.

	Salix	Shrubs	Grasses	Sedges	*Equisetum*	Forbs	Lichen	Mosses
Salix	1.00							
Shrubs	-0.19	1.00						
Grasses	0.23	0.01	1.00					
Sedges	0.37	-0.21	0.25	1.00				
Equisetum	-0.09	-0.21	0.01	-0.13	1.00			
Forbs	-0.01	-0.07	-0.05	-0.05	0.08	1.00		
Lichen	-0.73	-0.05	-0.50	-0.64	-0.13	-0.10	1.00	
Mosses	-0.36	0.42	-0.01	-0.22	-0.07	-0.11	0.02	1.00

n = 252

Table 3.6 Pearson correlation matrix of serum mineral levels across ranges in female yearlings during summer and mean calf weight (kg) and calf:cow ratio.

	Zn	P	Fe	Mg	Cu	Ca	Na	Se	Wt,	Calf:cow
Zn	1.00									
P	-0.92	1.00								
Fe	-0.33	0.67	1.00							
Mg	0.92	-0.99	-0.66	1.00						
Cu	0.60	-0.74	-0.70	0.76	1.00					
Ca	-0.49	0.64	0.56	-0.59	-0.06	1.00				
Na	0.01	-0.47	-0.93	0.44	0.39	-0.66	1.00			
Se	0.39	-0.66	-0.90	0.68	0.92	-0.21	0.70	1.00		
Weight	0.31	-0.01	0.60	0.00	-0.57	-0.28	-0.52	-0.74	1.00	
Cow:calf	0.39	-0.39	-0.14	0.35	-0.32	-0.90	0.30	-0.23	0.65	1.00

CHAPTER 4

Landscape variation in diet and $\delta^{15}N$ natural abundance in reindeer, Seward Peninsula, Alaska.

Abstract

The nitrogen (N) in tundra soils and vegetation is highly heterogeneous in concentration and isotopic signature; varying by orders of magnitude, both seasonally and across microsites. Domestic reindeer (*Rangifer tarandus tarandus*) grazing on discrete ranges of the Seward Peninsula, Alaska consume a wide variety of forages differing in N characteristics that may have consequential effects on protein assimilation and animal productivity. I show that $\delta\ ^{15}N$ values of plant growth forms consumed by reindeer on the Seward Peninsula vary significantly with shrubs ($-2.1^{0}/_{00} \pm 0.2$) and lichens ($-2.3^{0}/_{00} \pm 0.5$) being much more depleted than graminoids ($1.7^{0}/_{00} \pm 0.1$), forbs ($2.7^{0}/_{00} \pm 0.3$) and mushrooms ($4.0^{0}/_{00} \pm 0.6$). Reindeer consumed catkins, stems and young leaves of shrubs during snowmelt then shifted to a more ^{15}N enriched diet of graminoids and forbs later in summer. The ^{15}N value in collagen sequentially deposited in antler bone from spring until ossification was significantly correlated with the ^{15}N composition of the diet. Serum, red blood cells (RBC) and muscle $\delta\ ^{15}N$ values of all reindeer were more enriched than waste product, urine and feces, but serum was more enriched than RBC in this study, in contrast to other studies. Reindeer consuming proportionately more shrubs in early spring had a depletion of ^{15}N of hard and soft tissue that persisted throughout the year.

Calf weight was not related with isotopic signatures in antler and soft tissue, but was related with the absolute differential between summer and winter blood serum (R^2 =

0.91) suggesting that female reindeer in one herd were catabolizing more protein during winter and had lighter calves the following summer than adjacent herds. In herds with smaller mean calf weights , reindeer consumed proportionately more shrubs in early spring resulting in a strong correlation between $\delta\ ^{15}N$ signatures of antler collagen deposited in May and mean calf weight ($p = 0.004$, $R^2 = 0.96$). This relationship suggests female reindeer catabolizing body protein stores during late winter may be compensating by increasing intake of protein in the spring by consuming a higher proportion of shrubs in the diet.

Introduction

Nitrogen (N) makes up a large portion of the earth's atmosphere but for the most part is inert, while the biologically usable form is scarce and a limiting resource for many plants and animals. Animals have vastly higher N requirements than plants because they use proteins for structural building blocks and all metabolic processes, whereas plants use fiber for structure which is primarily composed of carbon. Animals also use N less efficiently than plants because a significant fraction is excreted as waste products while plants lose little N except as litter fall and root exudates. Because it plays such an essential role in all structural and metabolic processes for animals and is a limiting resource, the success in sequestering N greatly influences growth, reproduction, and survival (Mattson, 1980).

Nitrogen availability for plant growth is generally low in northern tundra soils. Low precipitation limits atmospheric input and low soil temperature inhibits chemical weathering of parent material and limits fixation and mineralization that severely inhibits nitrogen input and recycling rates (Bliss, 1962; Ellis, 1980; Dowding *et al.*, 1981). In addition to the low availability, nitrogen pools in soils and vegetation are highly heterogeneous in forms and concentrations varying by orders of magnitude, both seasonally and across microsites (Chapin *et al.*, 1980; Kielland, 1995; Kielland and Chapin, 1992; Schimel *et al.*, 1996; Weintraub and Schimel, 2005).

Many northern human populations use either wild or domestic populations of *Rangifer* for sequestering, harvesting and consumption of local environmental N. But, seasonal grazing patterns of domestic reindeer are often influenced by the action of

humans through herding. Since bioavailable N occurs in spatial and temporal patches across tundra grazing areas, the placement of animals to consume N rich forage should be based on both the current physiological demands of the animal and the foraging ecology of *Rangifer*.

Reindeer and caribou do not forage haphazardly, but select species that contain high concentrations of digestible N during the plant growing season (Klein, 1970; Finstad and Kielland, 2008) because growth of both hard (bone, hair) and soft tissue (muscle, organs) is at a maximum. Since many plant growth forms have distinctive N isotopic signatures (Schulze *et al.*, 1994, Nadelhoffer *et al.*, 1996; Kielland *et al.*, 1998), the N assimilated into various tissues of reindeer during synthesis may give clues on the environmental sources of consumed N.

Tissues of animals with different rates of nitrogen deposition and turnover can also provide information on sources of N in the diet. The isotopic signatures of tissues change seasonally in relation to sources of N in diets of ruminants (Barnett, 1994; Kielland, 2001). Isotopic signatures of soft tissue with fast turnover rates reflect the daily or weekly diet (Tieszen *et al.*, 1983), while hard tissue such as hair, feathers and bone reflects diet months or years prior (Tieszen *et al.*, 1983; Boutton *et al.*, 1984).

Hard tissue, like collagen in bone, is inert and can be used to estimate diet long after the animal has died and the soft tissue decomposed (Schell *et al.*, 1989). For example, differences in isotopic signature of sequential hoof layers of reindeer and caribou represent annual changes in diet composition (Barnett, 1994). Antlers of reindeer and caribou are shed during the winter and regrow during the summer months when

nutrient availability is high. Nitrogen in the form of collagen is laid down during the synthesis of cartilage as antlers are formed. In reindeer, cartilage formed during antler synthesis is vascularized so it does not undergo erosion by invading blood vessels as happens in cartilage of long bones (Rönning *et al.*, 1990). As a result, $\delta^{15}N$ deposition in sequential antler layers should temporally reflect dietary N during the growth period. Each successive layer of deposited nitrogen in antler bone may have a distinct isotopic signature indicating source (plant growth form) of protein from the environment. Since circulating N is used for synthesis of protein found in both hard and soft tissue alike, the isotopic signature of soft tissue, at any one time should correspond to the N signature of collagen in sequential layers of bone in antlers. Antlers are inert after ossification and could be used as an indicator of source of N in soft tissue.

The degree of isotope fractionization of body tissue has also been used to estimate body condition of animals (Hobson *et al.*, 1993). Tissues of animals under nutritional stress that are catabolizing body protein show a progressive enrichment of body tissue compared to animals with diets meeting maintenance requirements (Hobson *et al.*, 1993). In *Rangifer,* the lighter nitrogen in the waste product urea is recycled and used in place of dietary protein; therefore animal lean tissue should become even more enriched as recycled urea is used as the source of metabolic N instead of the diet.

Since the assimilation of N is critical for reproduction and calf growth in reindeer, correlating N uptake (source and flux) with productivity will give reindeer herders insight on the placement of animals across a heterogeneous N landscape to maximize animal production. Here I present data on $\delta^{15}N$ in both forage plants and reindeer across the

Seward Peninsula, Alaska. I hypothesized that forage plant growth forms will take up N from discrete pools in the environment and that differences in proportion of vegetation communities among reindeer ranges affect dietary selection and in turn, the differential uptake, assimilation and isotopic signature of N in various reindeer tissues. I further hypothesized that variation in uptake from different environmental pools of N, reflected in $\delta\ ^{15}N$ signatures of reindeer tissues, will be correlated with herd productivity.

Objectives

The objectives of this study were to; 1) estimate the $\delta^{15}N$ signatures of plant growth forms consumed by reindeer across ranges of the Seward Peninsula; 2) examine the relationship between seasonal diet composition and $\delta\ ^{15}N$ signatures of feces, antler, and soft tissue of reindeer; and 3) estimate if variation of $\delta\ ^{15}N$ signatures of reindeer tissues across herds can account for differences in calf weights. Samples were also collected from hunter-harvested Western Arctic caribou (WAC) and from caribou and reindeer housed at the Large Animal Research Station, University of Alaska Fairbanks (LARS-UAF) for comparison of isotopic signatures of tissue from animals with sources of dietary N other than the Seward Peninsula.

Study Site

This study was conducted on five reindeer grazing allotments (hereafter called ranges) extending from White Mountain (N64. 43, W163 28) to Shishmaref (N66 14, W166 07) each with its own distinctive mix of vegetation communities (Fig. 1), (Finstad and Kielland, 2008). The cold Bering Sea influences climate with persistent winds in winter and cool wet weather in summer. Generally, there is an increasing ratio of

graminoids to deciduous shrubs comprising the northern ranges than those in the southern Seward Peninsula (Swanson *et al.*, 1985; Finstad and Kielland 2005). The Weyiouanna range consists of wet and dry tundra where graminoids dominate especially sedges, *Eriophorum spp.* and *Carex aquatilis* with riparian willows found in relatively small drainages.

The Olanna range consists of wet tundra surrounding Brevig Mission, merging with dry tundra on lower slopes of hills and mountains to the north and east, while upper slopes are bald limestone and lava beds. Local weather is influenced by onshore winds from Grantley Harbor with cold persistent winds in winter with cool wet, foggy summers.

The Noyakuk range is dominated by deciduous shrubs in the floodplain surrounding the Imruk basin, a large brackish lake in the southern portion of the range and vast areas of tussock tundra extending northward to the windswept Kougarok Mountains.

The Davis Range consists of the coastal plains near Nome where grasses dominate to the more mountainous area to the north where woody shrubs predominate. The majority of the range is rolling valleys containing rivers, streams and lowlands that support a large number of deciduous shrubs while upland areas contain mostly graminoid species. The climate is transitional with cool, wet summers along coastal areas but much drier and warmer inland.

The Gray Range is dominated by the Fish River Delta which consists of coniferous trees, deciduous shrubs and tidal marshes. Upland slopes of dry and upland tundra surround this delta. The climate is maritime but uplands buffer the maritime winds

and precipitation so spring and summers are warm and dry which is indicated by the presence of substantial spruce forests that are absent from the surrounding coastal areas.

The Western Arctic Caribou Herd (WACH) calves on the arctic plain of the North Slope of Alaska during June. The North Slope Arctic Plain is dominated by graminoids in wet sedge meadow communities (White *et al.*, 1975).

Methods

Ten to 20 gram samples of reindeer forage plants were collected May through August 1996 and May through August 1997 as part of another study (Finstad and Kielland, 2008) on four sites on the Davis range, five sites on the Gray range and three sites on the Olanna range. The samples included deciduous shrubs: *Salix pulchra, S. alaxsensis, S. lanata, Betula nana, Vacciniun uliginosum*; graminoids: *Carex aquatilis, C. bigelowii, C. ramenskii, C. lyngbyaei, Eriophorum angustifolium, Eriophorum vaginatum, Arctophila fulva,* and *Calamagrostis canadensis*; forbs: *Artemisia arctica, Petasites frigidus, Equisetum spp., Hedysarum alpinum, Hippuris vulgaris, Epilobium spp., Ranunculus spp., Pedicularis spp.*; and lichens: *Cetraria cucullata, C. islandica, Cladina mitis/arbuscula,* and *Cladina rangiferina.* Ten samples each of *Salix pulchra, S. alaxsensis, Carex aquatilis, C. bigelowii, Epilobium spp., Pedicularis spp., Cetraria cucullata, Cladina mitis/arbuscula,* and *Cladina rangiferina* were collected on the Weyiouanna range during June 1996 and were pooled into plant form composites. All samples were dried for 48 hours at 60° C and then ground in a Wiley™ mill using a 1mm. screen.

Differences of naturally occurring stable isotopes of nitrogen

$$\delta^{15}N = ([^{15}N/^{14}N \text{ sample}/^{15}N/^{14}N \text{ standard}]-1) \times 1000), \quad (4.1)$$

where the standard is atmospheric N have been used to trace N cycling through ecosystems (reviewed by Peterson and Fry 1987). Natural abundance of ^{15}N of all plant, antler, serum, red blood cells, muscle, urine and fecal samples were assayed with a Europa Scientific 20-20 Continuous–flow Isotope Ratio Mass Spectrometer at the Alaska Stable Isotope Facility, University of Alaska Fairbanks. Accuracy of standard assays for peptone from meat (P7750, Sigma, Milwaukee, WI) were within $0.5^{0}/_{00}$.

The diet composition of reindeer across herds was determined by fecal microhistological analysis as part of another study (Table 4.1. Data taken from Finstad and Kielland, 2008). Sub-samples of the fecal collections were analyzed for natural abundance of $\delta^{15}N$. To test the hypothesis that the isotopic value of an animal's feces represents the relative contributions of different food items to its diet relies on the assumption that the N composition of the feces equals the weighted proportion of a food items N contribution to the diet times its isotopic value (Gannes *et al.*, 1997). Since N concentrations and δ^{15} N signatures are similar among species of forage on the Seward Peninsula, an estimate of the $\delta^{15}N$ signature of the feces based on the δ^{15} N input of growth forms in the diet can be estimated by the equation:

$$\delta^{15}N \text{ feces} = \sum \left[\frac{\% \text{ growth form in diet} \times [N]}{\sum \% \text{ growth form in diet} \times [N]} \times \delta^{15} \text{ N of growth form} \right] \quad (4.2)$$

where growth forms were shrubs, graminoids, forbs, lichen and mosses.

Mosses were not collected from the Seward Peninsula ranges but appeared in the microhistological fecal analysis so N concentrations and $\delta^{15}N$ values were taken from Kielland (2001).

Although velvet antlers were harvested in these herds during summer handlings, the animals were dispersed over large and rugged ranges and a number of reindeer escaped gathering and herding. These animals retain a full set of antlers through the winter months until casting in the spring. Cast antlers from adult females were collected from calving grounds during May 1996 and 1997 from the Davis (Nome), and Gray (White Mountain) ranges on the Seward Peninsula, Alaska.

Hard antlers were cut off immediately above the corona with a hack saw from adult females at the Noyakuk (Teller), Olanna (Brevig Mission) and Weyiouanna (Shishmaref) January (1997) reindeer handlings. Antlers were removed in the same manner from ten Western Arctic Herd (WAH) caribou killed by hunters in the Fish River Flats near White Mountain, Alaska in January 1997. Antlers were collected from 2 adult females, six yearling males, and 2 two year old caribou males. Ages of animals were estimated from body size and antler conformation. Cast antlers were collected from known age reindeer and caribou located at the LARS, UAF. These animals were fed a consistent diet of commercial pelleted ration, (Quality Texture™; QTX), and pasture throughout the antler growing season. All antlers were scrubbed with a stiff nylon brush and rinsed with distilled water to remove any residual blood, velvet, or other organic material and allowed to dry. Five grams of core trabecular bone was collected by drilling an 8mm wide x 60mm deep hole centered in the base parallel to the axis of the antler with

a handheld electric drill using a stainless steel masonry bit. The filings were collected in a plastic 100mm x 100mm plastic weigh boat. A five-gram sample of peripheral compact bone was also collected near the base of the antler. A stainless steel burring bit mounted on a hand held drill was used to grind off 1mm of bone from the surface of the antler base. The filings were collected in a plastic 100mm x 100mm plastic weigh boat. All samples were ground in a Wiley™ mill using a 20 mesh screen.

Subsamples of serum and red blood cells were partitioned from blood samples collected at the June 1996 Davis, Gray, and Olanna handlings. Blood was collected during winter slaughterings at all herds along with feces, and muscle tissue from the Noyakuk herd. Antlers, serum, red blood cells, muscle tissue and urine were collected during January and February 1997 from hunter killed WAH caribou. Serum, red blood cells, muscle tissue and urine were dried at 60° C for 48 to 72 hours in stainless steel vessels.

In this study, June 1996 and 1997 calf weights were used as an indicator of productivity linked to spring and summer forage quality as used in other *Rangifer* studies (Reimers, 1985, 1997). Methods for collecting calf weights and calculation of June 25th calf weight are described in Finstad and Kielland (2008).

Analysis of Variance (ANOVA) was used to compare differences in antler core (AC), antler periosteum layer (AP), feces, muscle, tissue, serum, and RBC $\delta^{15}N$ values (effects) due to range (factors). A general linear model (GLM) procedure using Systat 8.0 (1998) was used to evaluate the effects of differences in the proportions of plant growth forms in the diet on fecal, antler, soft tissue $\delta^{15}N$ concentrations and June calf weight.

Results

Nitrogen concentrations and ^{15}N values varied little among species within plant growth form so these results were pooled. Nitrogen concentrations and $\delta^{15}N$ values of different growth forms eaten by free ranging reindeer of the Seward Peninsula varied significantly ($F_{4,329,}$ 34.7, $p < 0.001$); ($F_{4,329}$ 95.6, $p < 0.001$); (Fig 4.2). Nitrogen concentration was highest in mushrooms (3.6% ± 0.1) and foliar tissue of shrubs (3.2% ± 0.1), followed by forbs (2.8% ± 0.1), then graminoids (2.2% ± 0.1) with lichens containing very low concentrations (0.3% ± 0.0). I found depleted $\delta^{15}N$ signatures in the foliar tissue of shrubs (-2.1‰ ± 0.2) and lichens (-2.3‰ ± 0.5) whereas, forbs (2.7‰ ± 0.3), graminoids (1.7‰ ± 0.1), and mushrooms (4.0‰ ± 0.6) were enriched. Concentrations of N and $\delta^{15}N$ values of the QTX and pasture (*Bromus*) fed to reindeer and caribou at LARS, UAF were 3.0% ± 0.1, 2.8‰ ± 0.1 and 2.8% ± 0.1, 1.6‰ ± 0.0, respectively (Fig. 4.2).

Prediction of the isotopic signature of feces by the input of $\delta^{15}N$ of each forage class in the seasonal diet (estimated by Equation 4.2) was significant ($p = 0.004$) although, R^2 was relatively low 0.24. The prediction equation was:

$$\delta^{15}N \text{ feces} = 42.7(\delta^{15}N \text{ input shrubs}) - 54.3(\delta^{15}N \text{ input graminoids}) - 34.1(\delta^{15}N \text{ input forbs}) + 32.7(\delta^{15}N \text{ input lichens}) + 91.2(\delta^{15}N \text{ input mosses}) + 92.4. \quad (4.3)$$

The concentration of N (Table 4.2) and $\delta^{15}N$ values (Table 4.3) of reindeer and caribou tissues varied significantly across ranges. Nitrogen concentration of antlers from LARS, UAF animals was significantly lower in both AC (5.9 ± 0.2%) and AP (6.9 ± 0.3%) layers than antlers from Seward Peninsula reindeer and WAH caribou (Table 4.2).

Isotopic signatures varied from -3.1‰ in urine to above 3.0‰ in the AP layer and muscle tissue (Fig. 4.3).

Serum $\delta^{15}N$ values varied significantly across ranges both in summer and winter (Table 4.3) and all serum was more enriched in winter than in summer but there was considerable variation among herds (Fig. 4.6). Isotopic signature of antler layer was a good predictor of serum values; n = 9, p = .001, R^2 = 0.80, but isotopic signatures of antler layers were better related with $\delta^{15}N$ values of serum collected during the corresponding time period in which the antler bone was deposited. Antler core (AC) values were better at predicting summer serum values (p = 0.25, R^2 = 0.85) than AP values (p = 0.46, R^2 = 0.56), but AP values (p < 0.001, R^2 = 0.95) were better at predicting winter serum values than AC values (p = 0.02, R^2 = 0.76).

Mean June 25th calf weight varied among herds in 1996 and 1997, whereas there was relatively little variation of June 25th calf weight between years within a herd (Table 4.4). Nitrogen concentrations of AC and AP across ranges were poor at predicting mean June 1997 calf weight (p = 0. 99, R^2 < 0.01; p = 0.95, R^2 < 0.01). AC and AP $\delta^{15}N$ values were also poor predictors of mean June calf weight (p = 0.22, R^2 = 0.43; p = 0.43, R^2 = 0.22). Summer 1996 and winter 1997 serum $\delta^{15}N$ values were not significantly related to June 1997 calf weight (p = 0.26, R^2 = 0.68), (p = 0.40, R^2 = 0.23).

Discussion

In the Subarctic, nutrient availability is low because nutrients are tied up in dead organic matter due to temperature limited decomposition (Van Cleve *et al.*, 1991). It has

been suggested that arctic plants in the same habitat absorb N from different pools with significant differences in $\delta^{15}N$ signatures (Schulze *et al.*, 1994). Trees and shrubs (-7.7 $^{0}/_{00}$ - -4.3$^{0}/_{00}$) are much more depleted in ^{15}N than graminoids (+0.9$^{0}/_{00}$) (Schulze *et al.*, 1994). The differences in $\delta^{15}N$ values of plant species may be explained by plants with different rooting depths tapping different N pools associated with soil horizon (Gebauer and Shulze, 1991), mycorrhizal association (Michelson *et al.*, 1996; Hobbie and Hobbie, 2004), or form of N absorbed (Kielland and Chapin, 1992). Data from this study supports this hypothesis as well, where graminoids that are uniformly rooted in the soil from the surface to 50 cm are enriched in ^{15}N with respect to the shrubs that access N in the 5-25 cm horizons (Schimel *et al.*, 1996) .

Lichens contain low concentrations of N (< 1.0 % N) that is absorbed in various forms, NH_4, NO_3, and amino acids, from rain, fog and surface flow (Dahlman *et al.*, 2004). During spring there is a pulse of available N (depleted in ^{15}N) originating from melting snow, soil litter, and release from winter killed soil microbes. This depleted N is dissolved in runoff that is accessible to shallow rooted vascular plants like shrubs which absorb a significant proportion of their seasonal nutrient requirements at this time (Kielland and Chapin, 1992). Lichens and mosses have a high capacity to absorb large quantities of water and undoubtedly soak up N rich spring runoff from the melting snowpack (Kielland, 1997). Reindeer and caribou are often seen grazing on lichens along melting snowpacks (Eastland *et al.,* 1989). This lichen may not only be more succulent but may exhibit an ephemeral increase in N concentration because the absorbed runoff may contain concentrations of N many times the uptake capacity of lichen. This N is

subsequently leached out of lichen by precipitation events and also becomes diluted as lichens begin to photosynthesize after snowmelt.

Although diet determines the overall isotopic signature of tissues of animals considerable variation among different tissues exists within individual animals. Results presented here are in agreement with other studies, where serum, red blood cells and muscle are more enriched than waste products, urine and feces (Steele and Daniel, 1978; Pearson *et al.*, 2003), but serum was more enriched than RBC in this study (Fig. 4.3). Bone, because of its metabolic longevity, usually is the most enriched tissue of the body however; N metabolism is different in antler bone than skeletal bone. The N deposited as collagen in antler cartilage is not replaced later during bone synthesis but instead is embedded in the inert matrix of the antler (Rönning *et al.*, 1990). This likely explains why $\delta^{15}N$ values in AC were more depleted than soft tissues (Fig. 4.3).

Turnover experiments have demonstrated that diet-switching influences $\delta^{15}N$ levels of body tissue (Peterson and Fry, 1987). For example, seasonal variations in proportions of forage consumed are reflected in $\delta^{15}N$ hoof values and contain a record of foraging behavior the previous 9 to 12 months (Kielland, 2001). Rumen content and hoof layer $\delta^{15}N$ analysis of caribou herds in Alaska show correlated enrichments during early spring and autumn when forbs and graminoids predominate in the diet compared to depleted summer values when caribou are grazing on a higher proportion of deciduous shrubs (Barnett, 1994). In this study, the enrichment in $\delta^{15}N$ in reindeer antler and soft tissue deposited across the growing season corresponds to the shift in diet from deciduous shrubs to graminoids (Fig. 4.5; Table 4.1). In all free ranging WAC and reindeer herds of

this study, diets shifted from shrub based in spring to graminoid based later in summer (Table 4.1), whereas the diets of LARS deer remained constant throughout the year. Antler periosteum (AP) bone was enriched in ^{15}N compared to AC in all free ranging reindeer and caribou, while there was very little differentiation between layers of bone in the antlers of LARS animals (Fig. 4.5). These data suggest that layers of collagen deposited during the antler growing season provide an index of the proportions of different plant growth forms in the diet at the time the collagen was being deposited. Although AP was biologically inert months before blood was collected in winter, the $\delta^{15}N$ values of AP and winter serum should be correlated. Since deposition of N in lean tissue and organs is greatly reduced in animals having reached body condition thresholds during fall (Chan-McLeod *et al.*, 1994), then there should be minor changes in tissue values going into winter if they remain in nitrogen balance. Results of this study support my hypothesis that ^{15}N signatures in AC and AP are good predictors of source of N (plant growth form) consumed by reindeer. Soft tissue and antler collagen synthesized simultaneously have correlated ^{15}N signatures. Because antlers are biochemically inert they may provide a bioindicator of foraging history of the animal long after soft tissue has decomposed.

Many techniques are used for conducting diet and habitat studies of free ranging animals, particularly such wide ranging species as reindeer and caribou. Each technique, while contributing to the understanding of foraging ecology, has its respective weaknesses. Visual observations of feeding behavior are subjective and imprecise. Fecal analysis gives biased estimates of forages consumed, as plants differ in digestibility and

fragmentation occurs during digestion (Boertje, 1981). Rumenal or esophageal fistulated animals are usually tethered restricting free movement during grazing. Analysis of stomach contents does not adequately represent diet selection through time. The shifting of isotopic signatures in other hard tissues such as hooves has been used to estimate shifts in diet of other large ungulates throughout a years time (Kielland, 2001), however the layers of collagen in antlers are deposited exclusively during the months when foraging conditions are assumed to have the greatest effect on animal productivity (Reimers, 1997).

In other studies with ruminants, fecal $\delta^{15}N$ values reasonably matched those of dietary N inputs (Steele and Daniel, 1978; Barboza and Parker, 2006). In this study the fecal $\delta^{15}N$ was significantly related to the proportional intake of forage growth forms consumed throughout the spring and summer. However, it could only predict about 20% of the variation in dietary $\delta^{15}N$. Proteins in forage have various solubilities and digestibilities that will likely "steer" N into different metabolic pathways (Van Soest, 1994). Isotopic composition of animal tissue is generally enriched by 3 to 6 $^{0}/_{00}$ relative to the diet. This enrichment occurs during the many metabolic processes that fractionate stable isotopes after consumption by animals. Transamination of nitrogen in amino acids favors the lighter isotope resulting in lighter end products and enrichment for the substrate amino acids (Macko *et al.*, 1986). Thus, depending upon the pathways and transamination reactions involved, individual amino acids can differ greatly from the source material from which they were derived (Macko *et al.*, 1987). This is especially true in ruminants where protein entering the rumen undergoes proteolysis and the

resultant amino acids undergo a variety of deaminations and transaminations as nitrogen is moved from one microbial pool to another before being digested and absorbed in the small intestine. Bacterial protein in the rumen undergoes a much different metabolic route than protein contained in ruminal protozoa, whereas even the ruminal protozoa protein may have gone through a phagotrophic, autotrophic, or saprozoic pathway with different fractionizations before being digested in the small intestine. Some dietary protein even "escapes" ruminal action and reaches the small intestine as undegraded protein having gone through fewer metabolic processes and less enrichment. If the diet of a ruminant consists of a diversity of forages containing proteins of various digestive characteristics moving along any number of metabolic (enrichment) pathways then the ability to accurately predict dietary N inputs of a diverse diet from fecal $\delta^{15}N$ may be limited.

Typically, *Rangifer* reduce intake (Tyler *et al.*, 1999) and body protein deposits decline during winter (Gerhart *et al.*, 1996). Reindeer adopt a strategy to conserve body protein during winter by the recycling of urea but will also use lean tissue to meet metabolic demands of critical tissues when dietary intake of N is lower than maintenance requirements (Parker *et al.*, 2005). Reindeer with dietary intake less than maintenance will begin to catabolize protein in muscle and organ tissue to meet energy and protein demands, thus increasing fractionation as the animal continues to remain in a negative energy and/or N balance. One would expect minimal change in tissue $\delta^{15}N$ from fall to late winter of reindeer with good energy reserves and adequate N in the diet. Animals with a negative N balance would be expected to have more enriched $\delta^{15}N$ tissue values

than animals in a more neutral or positive N balance (Hobson *et al.*, 1993). Pregnant reindeer may be most vulnerable to N deficits in late winter because stores of body protein may have been depleted because of demands for both fetal growth and maintenance. Female *Rangifer* in poor winter body condition have smaller fetuses (Adamczewski *et al.*, 1987) and calves (Reimers, 1997). An increase in mass loss during winter often results in a reduction of milk production and growth of calves (Rognmo *et al.*, 1983) so one would predict female reindeer exhibiting relatively enriched $\delta^{15}N$ tissue values to have lighter calves. In this study, data on calf weight and serum $\delta^{15}N$ in parturient female reindeer does not support this parsimonious hypothesis. Across 5 reindeer herds I failed to detect a significant inverse relationship between serum $\delta^{15}N$ of parturient females and calf weight ($p = 0.46$). Indeed, the herd with the lowest calf weight (Davis) had the most depleted $\delta^{15}N$ tissue values (Fig. 4.5). However, the enrichment in $\delta^{15}N$ serum values from summer to winter was greater in the Davis herd where calf weights were lowest compared to other herds. Reindeer catabolizing a larger proportion of their body protein during winter will have a larger serum $\delta^{15}N$ differential between summer and winter values with less body protein to contribute to fetus development and lactation. The differential between summer 1996 and winter serum 1997 $\delta^{15}N$ values was related to June calf weight $p = 0.2$, $R^2 = 0.91$ (Fig. 4.6). These data suggest that the relative difference between summer and winter serum $\delta^{15}N$ signatures was correlated with the degree of protein catabolization in female reindeer during winter and subsequent calf weight.

Reindeer on the Seward Peninsula begin growing new antlers in mid to late May (Tom Gray, reindeer herder White Mountain, personal observation) when collagen (N) is being laid down in the AC layer. The proportion of shrubs in the May diet was highly correlated with AC $\delta^{15}N$ values ($p = 0.007$; $R^2 = 0.99$), (Fig 4.7). Weight gain after parturition in female reindeer is inversely correlated with spring body condition, but lighter females still reach a lower peak mass in autumn compared to animals starting in good spring body condition (Gjøstein *et al.*, 2004). Hence, one would expect females with depleted protein deposits to increase the proportion of protein in their diets to support lactation and to replete lean and visceral mass. Leaves of most shrubs, graminoids and forbs on the Seward Peninsula do not emerge until June (Finstad and Kielland, 2008) but many shrubs are translocating N to stems and leaf buds to support rapid leaf expansion during greenup and have high protein concentrations (Chapin *et al.*, 1980). Catkins, stems and leaf buds of shrubs began appearing in diets of Seward Peninsula reindeer during May but proportions vary among herds (Table 4.2, taken from Finstad and Kielland, 2008). Female reindeer in herds with smaller June calves may be consuming more shrubs in the May diet to compensate for lower protein reserves. The proportion of shrubs in the May diet was highly inversely correlated with June calf weight ($p = 0.004$; $R^2 = 0.99$), (Fig. 4.8).

AC $\delta^{15}N$ values were depleted by the proportion of shrubs in the May diet, but AP $\delta^{15}N$ values were enriched in all herds because the proportion of graminoids and forbs in the diet increased in summer. June calf weight was correlated with the proportion of shrubs in the May diet so June calf weight should be related with the $\delta^{15}N$ ‰ differential

between AC and AP. June calf weight was significantly predicted by the ‰ differential between AC and AP ($p = 0.004$; $R^2 = 0.96$), (Fig. 4.9).

Tissues from herds that are more depleted in May remain depleted even though the diet becomes much more enriched later in summer and fall (Fig. 4.5; Table 4.1). Forages contain a variety of anti-herbivory compounds that influence the digestibility and the cycling of N through the digestive system of ruminants (Robbins *et al.*, 1987). The binding of condensed tannins (CT) with proteins is influenced by both the structure and molecular weights of both the CT and the dietary proteins (Clausen *et al.*, 1990). This binding can reduce the degradation of forage proteins in the rumen, most likely as a result of reducing the function and/or population size of proteolytic rumen bacteria. Undegraded protein, which often contains higher proportion of essential amino acids (EAA) than microbial protein, passes through the rumen entering the abomasum where it is hydrolyzed and absorbed by the small intestine (Min *et al.*, 2003). These "escape" amino acids, having undergone less fractionization, most likely will have a $\delta^{15}N$ signature more closely related to the diet than amino acids used in the synthesis of body protein originating from microbial protein. Newly emerging leaves of shrubs often contain CT which probably explains the lower digestibility of emergent shrub leaves on the Seward Peninsula (Finstad and Kielland, 2008). This dietary protein may work its way through the digestive tract of reindeer and be assimilated in body protein with little fractionization. Growth hormones are at a peak during spring to support the rapid deposition of protein in lean tissue, particularly antler and muscle (Suttie and Webster, 1995; Barboza and Parker, 2006). Thus, by the interaction of a distinctive $\delta^{15}N$ signature

of the diet and high N assimilation rates spring diets could leave a legacy in the tissues of reindeer. A moderate concentration of CT in the diet of ruminants has been shown to improve animal production, presumably because CT reduces rumen forage protein degradation (Min *et al.*, 2003) and may be the reason female reindeer in some herds are consuming more forage with higher concentrations of protein and CT during early spring.

Although limitations of digestible energy in the diet can influence nutritional status and reproductive performance in *Rangifer* (Cameron *et al.*, 1993), this is probably not the case for Seward Peninsula reindeer. During the time of this study stocking densities were generally low (> 2.0 reindeer km^2; RRP unpublished data http://reindeer.salrm.uaf.edu), lichen, a source of readily digestible energy, was common on all ranges (Swanson *et al.*, 1985) with minimal use by reindeer and caribou (NRCS/BLM annual report, 1996, 1997). Protein intake is especially important for juvenile *Rangifer* because they preferentially deposit body protein over body fat, which directly influences growth and subsequent conception rates (McEwan and Whitehead, 1970; Allaye-Chan, 1991; Ropstad *et al.*, 1991. It has been suggested that caribou calf growth and reindeer body size is a function of spring and summer forage quality, i.e. digestible protein (Klein, 1970; Post and Klein, 1999; Reimers, 1997) and is likely responsible for the difference in June calf weights of this study. June calf weights on the Seward Peninsula have been shown to be positively correlated with reindeer ranges containing a greater proportion of high protein *Salix* and *Carex spp.* (Finstad and Kielland, 2005). In this study herds with heavier June calves and lower proportion of shrubs in the May diet were the same herds that had a higher abundance of protein rich

willow and sedge species on their range during summer (Finstad and Kielland, 2005). This relationship suggests that reindeer on ranges with less abundance of high protein forages during summer may be compensating by consuming a higher protein diet immediately after parturition.

Results of this study suggest that isotopic signatures of N in antlers are a good bioindicator of production of reindeer herds on the Seward Peninsula. However, caution should be exercised in extrapolating results of this study to other regions and *Rangifer* populations. Forage composition of other *Rangifer* grazing areas would likely be different than found on the Seward Peninsula. The relationship between tissue $\delta^{15}N$ values and production is apparently due to the pattern of consumption of a specific diet. Interpretation of tissue $\delta^{15}N$ values must be made in context of the species and chemical characteristics of the forage found in regional diets of a *Rangifer* population.

In conclusion, I showed that $\delta\ ^{15}N$ signatures of plant growth forms consumed by reindeer across five ranges on the Seward Peninsula varied significantly with shrubs and lichens being much more depleted in ^{15}N than graminoids and forbs. Reindeer began consuming shrubs during and after snowmelt then shifted to a more enriched diet of graminoids later in summer. The abundance of ^{15}N in layers of antler bone was significantly correlated with that of the seasonal diet as were soft tissue $\delta^{15}N$ values; supporting my hypothesis that antler may be used as a bio-indicator of environmental source of dietary N.

June calf weight was not related with absolute isotopic signatures in antler and soft tissue. Rather, the isotopic differential between summer and winter $\delta^{15}N$ values of

soft tissue, suggestive of increased catabolism of body protein, was significantly related with lower calf weight. Reindeer in herds with smaller June calves consumed more shrubs in the May diet, presumably to compensate for lower protein reserves. AC $\delta^{15}N$ values were depleted by the proportion of shrubs in the May diet, but AP $\delta^{15}N$ values were enriched in all herds because the proportion of graminoids and forbs in the diet increased in summer. June calf weight was significantly predicted by the $\delta^{15}N$ ‰ differential between AC and AP supporting my hypothesis that $\delta^{15}N$ values in reindeer antlers can predict reindeer production on the Seward Peninsula.

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Figures

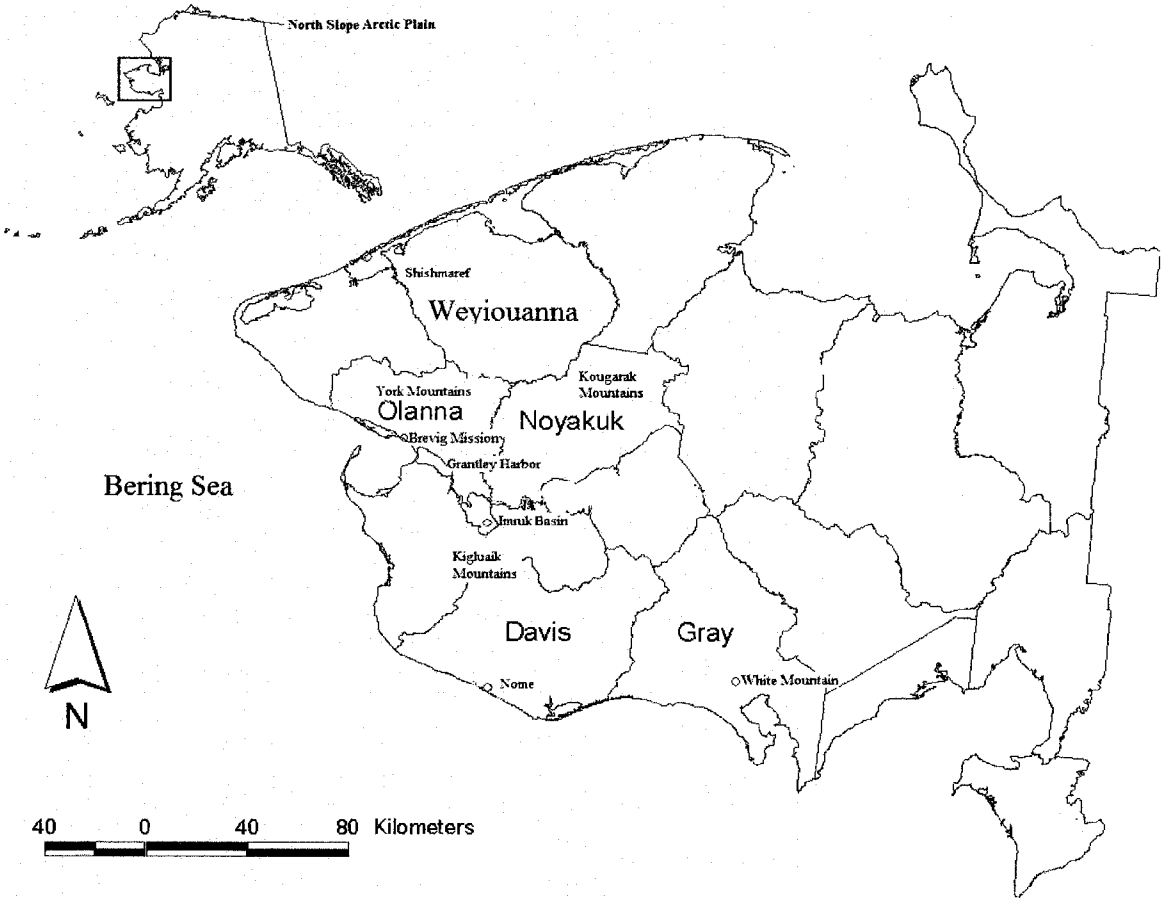

Figure 4.1 Reindeer ranges of the Seward Peninsula, Alaska where study was conducted.

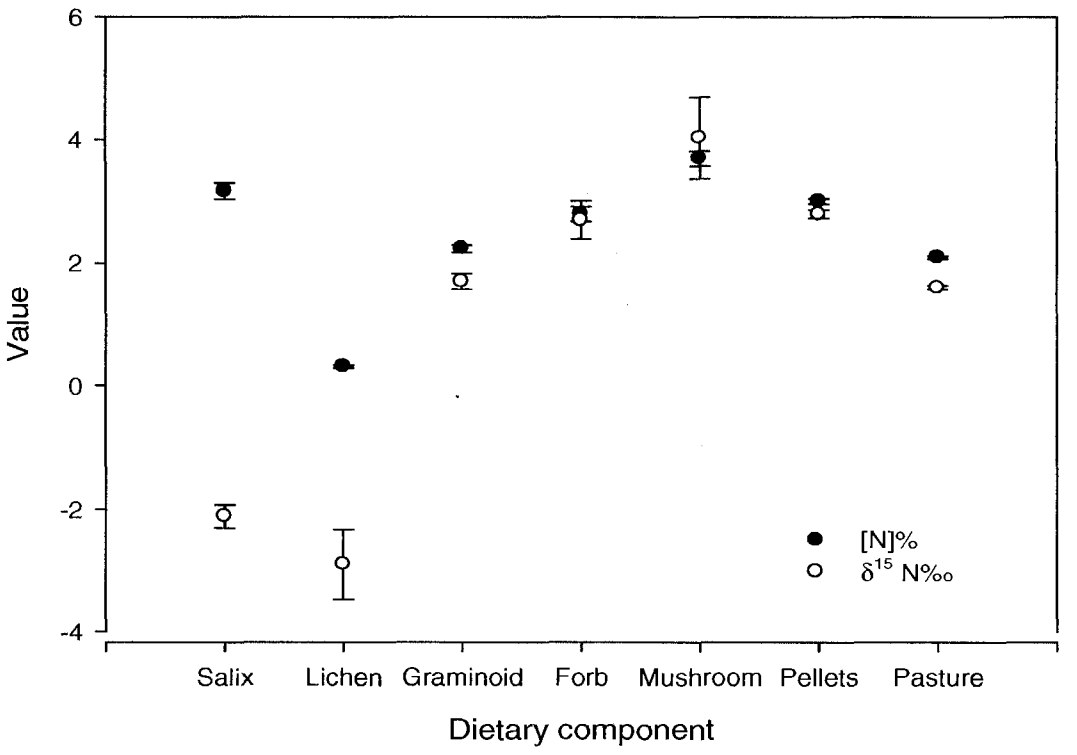

Figure 4.2 N concentration (%) and δ^{15}N signature ($^{0}/_{00}$) of dietary components eaten by free ranging reindeer on the Seward Peninsula and by reindeer and caribou at the Large Animal Research Station, Fairbanks, Alaska (commercial pellets and pasture). Mean ± SE. (n = 292).

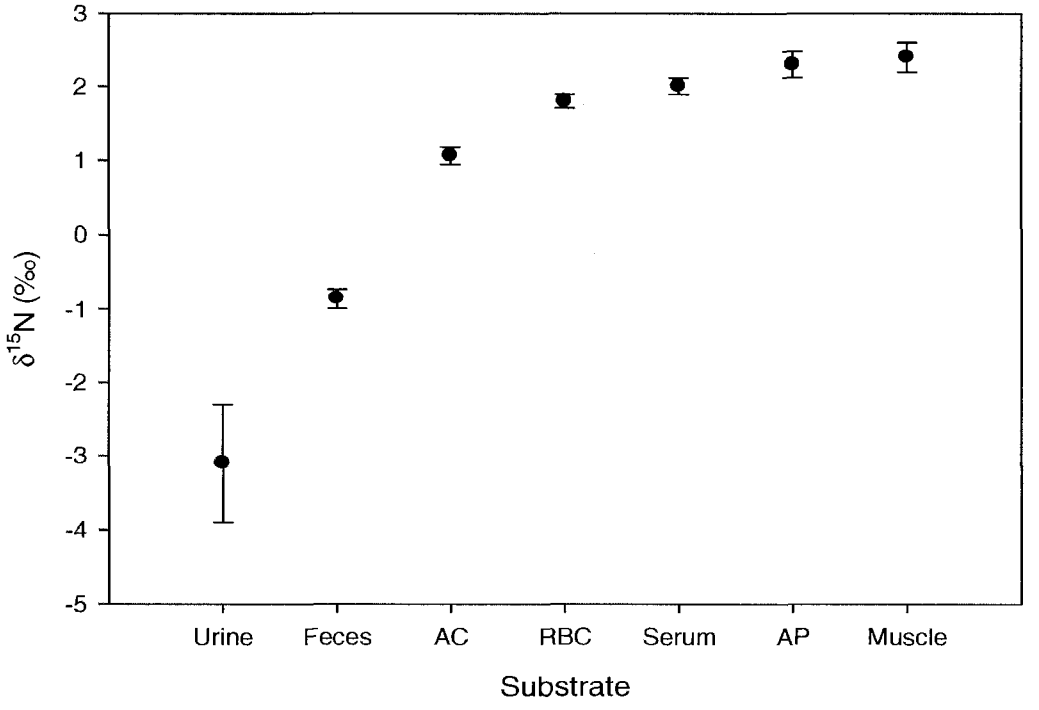

Figure 4.3 δ^{15}N values of reindeer and caribou tissue on the Seward Peninsula during winter. AC = antler core; RBC = red blood cells; AP = antler periosteum. Mean ± SE. (n = 326).

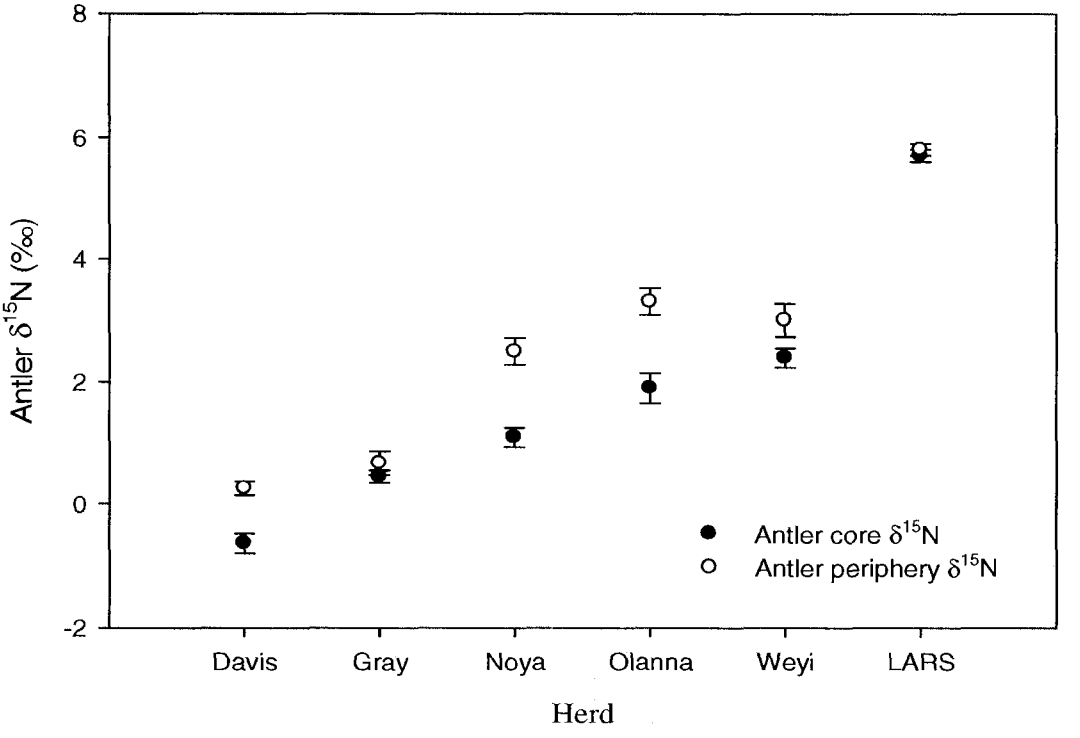

Figure 4.4 δ^{15}N values of samples taken from the core and periphery of antlers collected from reindeer herds across the Seward Peninsula and the Large Animal Research Station (LARS) University of Alaska. Noya = Noyakuk; Weyi = Weyiouanna. Mean ± SE. (n = 174).

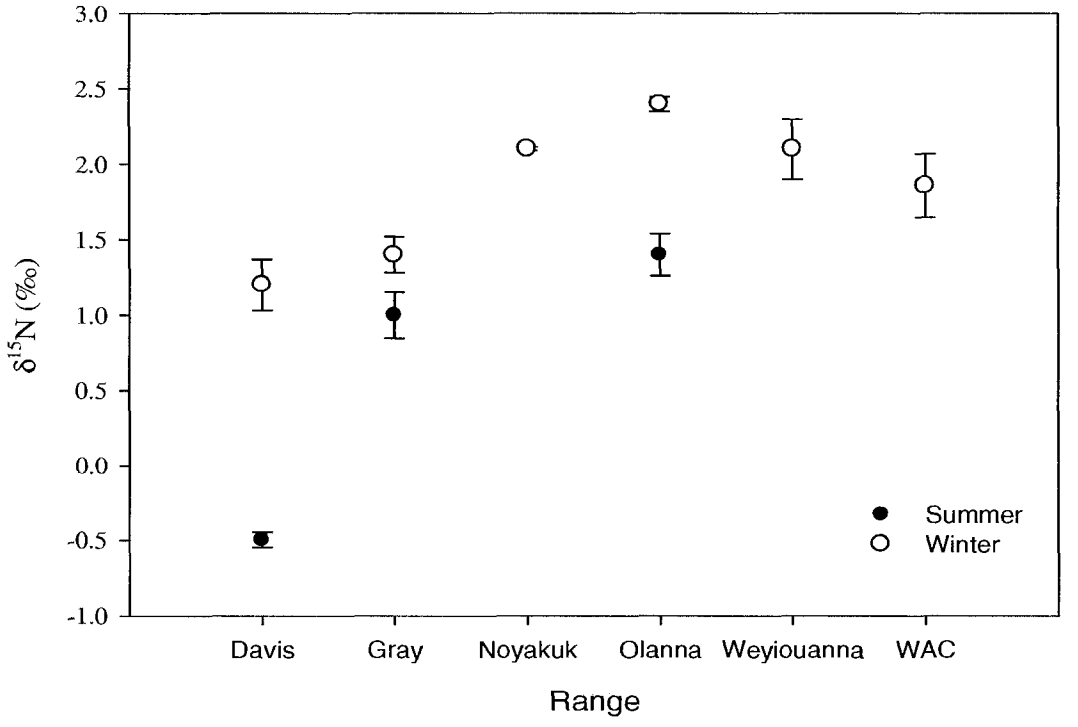

Figure 4.5 Serum δ ^{15}N values during summer and winter from Seward Peninsula reindeer and Western Arctic caribou (WAC). Mean ± SE.

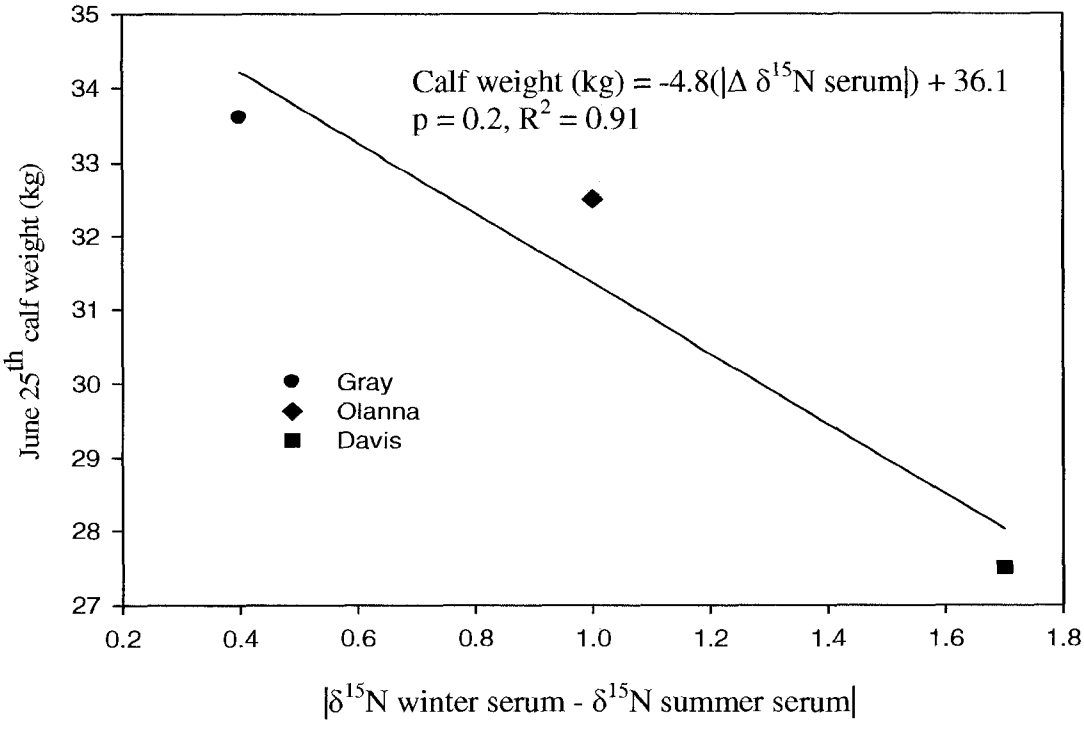

Figure 4.6 Relationship of differential between summer and winter serum $\delta^{15}N$ ‰ and 1997 June calf weight of Seward Peninsula reindeer (calf weight, n = 825; serum, n = 81).

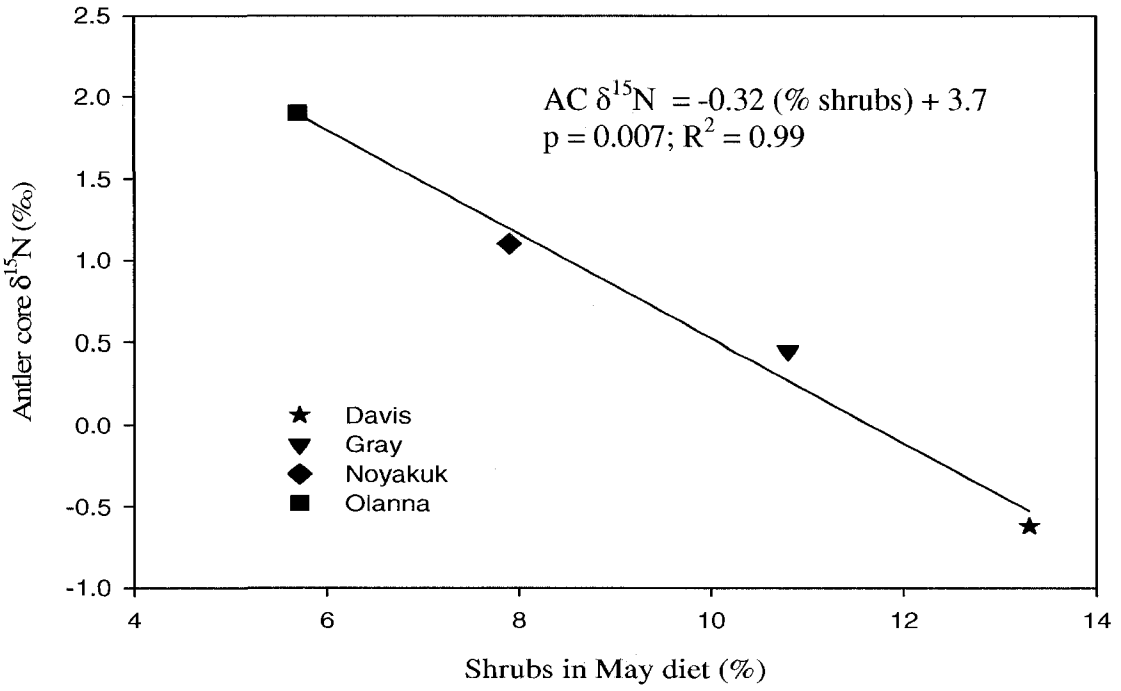

Figure 4.7 Relationship between the percentage of shrubs in the May diet and $\delta^{15}N$ concentration in the antler cores (AC) of reindeer from four herds on the Seward Peninsula, Alaska. (n = 178).

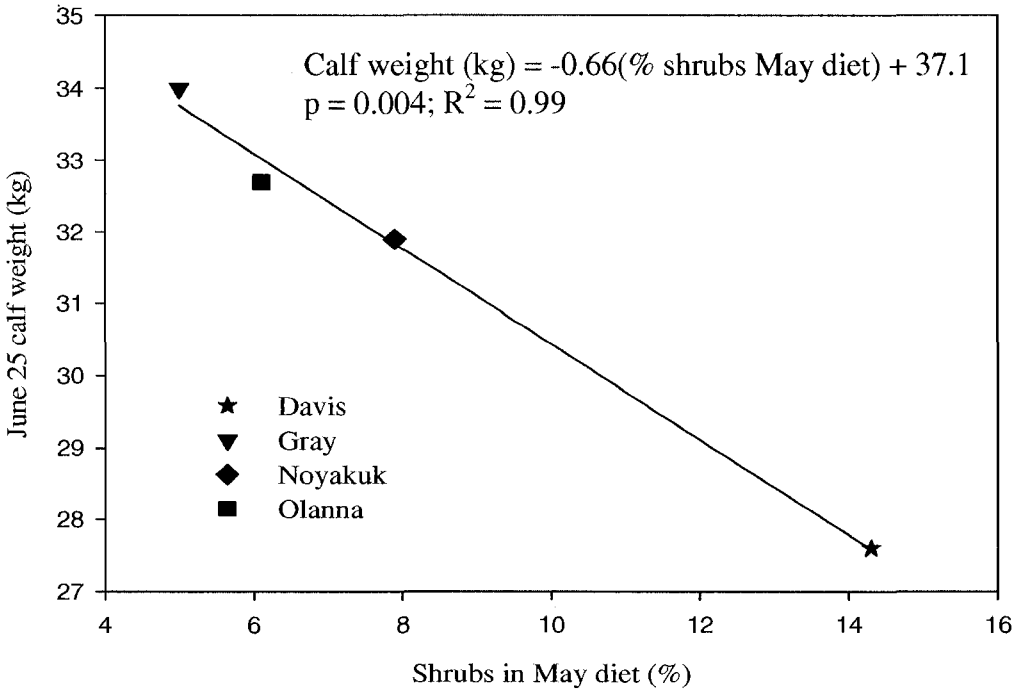

Figure 4.8 Relationship between percentage (%) of shrubs in the May diet of reindeer and June calf weights the following year in herds across the Seward Peninsula, Alaska. (calf weights, n = 965; diet, n = 81).

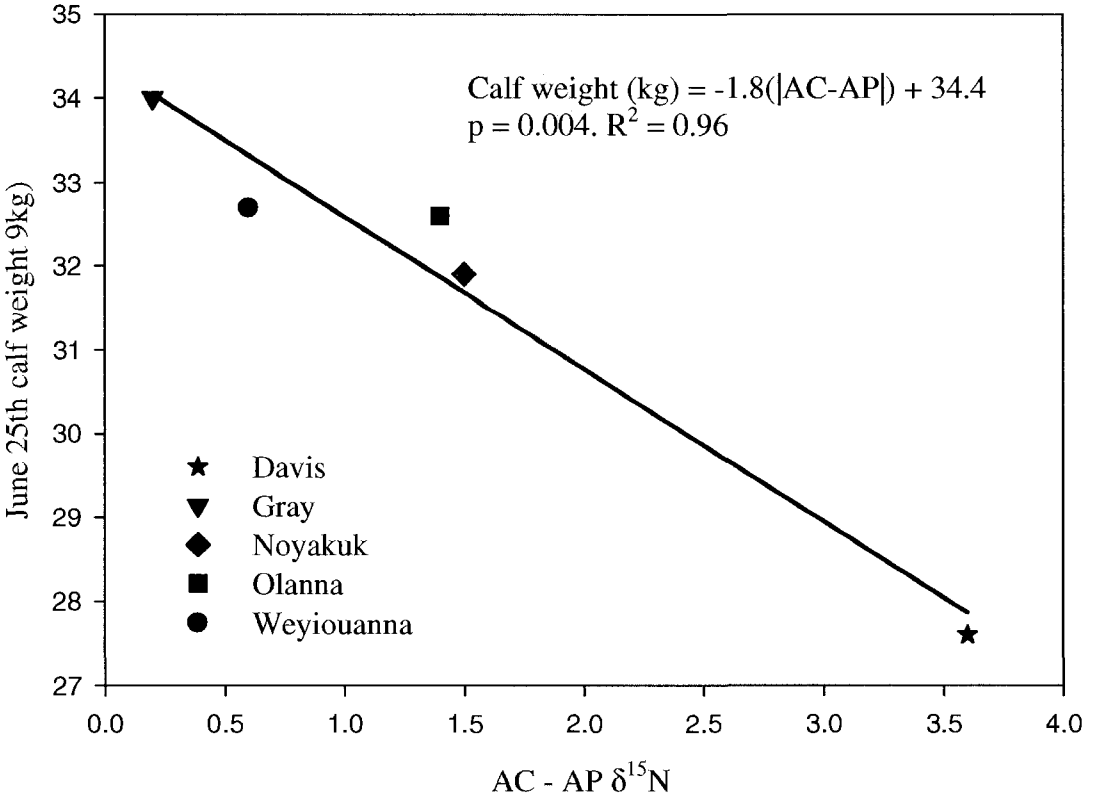

Figure 4.9 Relationship of $\delta^{15}N$ ‰ differential between antler core and antler periosteum and 1997 June calf weight of Seward Peninsula reindeer (calf weight n = 825; antler n = 68)

Tables

Table 4.1 Percentage of plant growth forms found in digestibility corrected seasonal diets of Seward Peninsula reindeer estimated by microhistological analysis of pooled fecal samples. Comparison of seasonal column means across ranges * $p < 0.05$; ** $p < 0.01$; n.s. = not significant. Data taken from Finstad and Kielland (2008).

		Salix	Shrubs	Grass	Sedge	Equi	Forbs	Lichen	Mosses	Rhizome
Davis	Spring	4.1 ± 0.6	10.2 ± 1.3	4.4 ± 0.9	9.5 ± 0.9	3.5 ± 0.1	1.6 ± 0.4	56.2 ± 2.1	10.4 ± 1.1	0.3 ± 0.2
	n / p	36 / n.s	36 / **	36 / n.s.	36 / n.s.	36 / **	36 / n.s	36 / *	36 / n.s.	36 / n.s.
	June	19.5 ± 3.0	3.7 ± 1.0	4.2 ± 0.8	9.6 ± 1.4	6.7 ± 1.9	2.7 ± 1.0	49.0 ± 3.2	4.4 ± 0.7	0
	n / p	21 / *	21 / n.s	21 / n.s	21 / **	21 / *	21 / n.s	21 / *	21 / **	21 / n.s.
	July	12.5 ± 1.9	2.4 ± 0.6	2.3 ± 0.8	11.8 ± 1.9	3.2 ± 1.0	3.4 ± 0.6	62.3 ± 3.4	2.1 ± 0.4	0
	n / p	23 / n.s.	23 / n.s.	23 / n.s.	23 / **	23 / *	23 / n.s	23 / **	23 / **	23 / n.s
	Fall	3.8 ± 1.4	2.7 ± 0.9	1.2 ± 0.5	6.7 ± 4.7	0.00	1.7 ± 0.6	81.3 ± 3.5	2.7 ± 1.5	0
	n / p	6 / n.s	6 / n.s	6 / n.s	6 / n.s	6 / *	6 / n.s.	6 / *	6 / n.s	6 / n.s
	Winter	4.0 ± 1.5	2.3 ± 0.7	4.6 ± 1.4	10.7 ± 1.1	1.2 ± 0.7	0.9 ± 0.09	71.8 ± 3.0	5.4 ± 1.9	0
	n / p	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / **	4 / n.s	4 / n.s	4 / n.s
Gray	Spring	2.4 ± 0.7	2.6 ± 0.7	2.5 ± 0.6	8.6 ± 1.4	4.3 ± 2.2	2.4 ± 2.0	65.1 ± 2.3	8.6 ± 1.3	3.5 ± 1.6
	n / p	29 / n.s	29 / **	29 / n.s.	29 / n.s.	29 / **	29 / n.s	29 / *	29 / n.s.	29 / n.s.
	June	26.6 ± 3.2	1.7 ± 1.1	7.3 ± 1.6	25.1 ± 3.0	0.9± 0.4	0.8 ± 0.9	36.8 ± 5.5	0.6 ± 0.2	0.2 ± 0.1
	n / p	23 / *	23 / n.s	23 / n.s	23 / **	23 / *	23 / n.s	23 / *	23 / **	23 / n.s.
	July	30.5 ± 4.8	1.2 ± 0.8	8.5 ± 1.9	31.8 ± 3.9	1.2 ± 0.7	1.8 ± 0.9	24.1 ± 7.2	0.6 ± 0.9	0.3 ± 0.3
	n / p	15 / n.s.	15 / n.s.	15 / n.s.	15 / **	15 / *	15 / n.s	15 / **	15 / **	15 / n.s
	Fall	1.4 ± 0.7	3.9 ± 0.8	4.3 ± 0.4	8.1 ± 1.4	5.7 ± 1.4	2.3 ± 1.1	68.7 ± 2.3	3.6 ± 0.5	1.0 ± 0.3
	n / p	24 / n.s	24 / n.s	24 / n.s	24 / n.s	24 / *	24 / n.s.	24 / *	24 / n.s	24 / n.s
	Winter	0.8 ± 0.3	3.8 ± 0.9	2.9 ± 1.0	9.6 ± 1.9	0.2 ± 0.1	0.16 ± 0.3	71.9 ± 3.6	9.4 ± 2.3	1.3 ± 0.8
	n / p	18 / n.s	18 / n.s	18 / n.s	18 / n.s	18 / n.s	18 / **	18 / n.s	18 / n.s	18 / n.s

Table 4.1continued

		Salix	Shrubs	Grass	Sedge	Equi	Forbs	Lichen	Mosses	Rhizome
Kakarak	June	35.7 ± 2.6	1.6 ± 0.7	1.8 ± 0.7	19.9 ± 5.9	2.5 ± 1.4	3.4 ± 1.6	30.6 ± 3.0	4.5 ± 1.9	0
	n / p	4 / *	4 / n.s	4 / n.s	4 / **	4 / *	4 / n.s	4 / *	4 / **	4 / n.s.
Noyakuk	Spring	2.4 ± 0.5	5.5 ± 1.2	2.5 ± 1.4	7.8 ± 2.7	4.4 ± 1.9	1.3 ± 0.7	68.8 ± 4.4	7.3 ± 2.0	0
	n / p	7 / n.s	7 / *	7 / n.s.	7 / n.s.	7 / **	7 / n.s	7 / *	7 / n.s.	7 / n.s.
	June	41.4 ± 9.6	4.7 ± 4.7	2.6 ± 0.6	7.8 ± 3.8	0	1.2 ± 1.2	38.9 ± 14.4	3.4 ± 3.4	0
	n / p	2 / *	2 / n.s	2 / n.s	2 / **	2 / *	2 / n.s	2 / *	2 / **	2 / n.s.
	Winter	5.4 ± 1.6	7.3 ± 0.9	1.2 ± 0.6	3.6 ± 2.2	0	2.8 ± 1.0	76.6 ± 3.1	3.1 ± 0.7	0
	n / p	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / n.s	4 / **	4 / n.s	4 / n.s	4 / n.s
Olanna	Spring	4.2 ± 1.2	1.9 ± 0.6	3.3 ± 0.7	8.8 ± 1.6	14.2 ± 5.1	1.0 ± 0.5	56.0 ± 5.1	8.2 ± 1.6	2.5 ± 1.0
	n / p	9 / n.s	9 / *	9 / n.s.	9 / n.s.	9 / **	9 / n.s	9 / *	9 / n.s.	9 / n.s.
	June	13.9 ± 3.1	1.6 ± 0.8	6.3 ± 2.2	11.6 ± 2.1	8.5 ± 2.3	0.6 ± 0.3	49.4 ± 3.2	4.8 ± 0.6	3.3 ± 2.6
	n / p	9 / *	9 / n.s	9 / n.s	9 / **	9 / *	9 / n.s	9 / *	9 / **	9 / n.s.
	July	17.0 ± 2.7	3.9 ± 2.2	1.4 ± 0.6	12.1 ± 3.9	7.2 ± 1.8	3.0 ± 1.0	48.8 ± 5.0	5.9 ± 1.2	0.8 ± 0.6
	n / p	9 / n.s.	9 / n.s.	9 / n.s.	9 / **	9 / *	9 / n.s	9 / **	9 / **	9 / n.s
	Winter	0	7.7	0.6	2.5	0	0	76	13.3	0
	n / p	1 / n.s	1 / n.s	1 / n.s	1 / n.s	1 / n.s	1 / **	1 / n.s	1 / n.s	1 / n.s
Weyiouanna	June	40.1 ± 3.4	2.7 ± 0.9	4.7 ± 0.9	12.0 ± 3.3	4.4 ± 1.4	2.3 ± 1.3	31.4 ± 4.5	1.8 ± 0.5	0
	n / p	9 / *	9 / n.s	9 / n.s.	9 / **	9 / *	9 / n.s.	9 / *	9 / **	9 / n.s.

Table 4.2 N concentrations of feces and tissue from reindeer on five ranges on the Seward Peninsula, Western Arctic caribou (WAC) and captive reindeer and caribou. Means ± S.E. W = winter. S = summer. AC = antler core, AP = antler periosteum, RBC = red blood cells. Comparison of column means; * $p < 0.05$; ** $p < 0.01$; n.s. = not significant.

	% Nitrogen							
	Winter sample							Summer
Range	AC	AP	Fecal	Muscle	Serum	RBC	Urine	Serum
Davis	7.1 ± 0.13	8.1 ± 0.2	3.2 ± 0.1		13.0 ± 0.1			13.8 ± 0.1
n/p	15/**	12/**	14/**S		8/**			6/**
Gray	7.2 ± 0.19	8.7 ± 0.3	3.1 ± 0.0		13.4 ± 0.1			13.3 ± 0.1
n/p	13/**	5/**	7/**S		11/**			13/**
Noyakuk	6.8 ± 0.2	7.9 ± 0.3	2.0 ± 0.0	13.2 ± 0.3	13.0 ± 0.1	15.3 ± 0.1		
n/p	21/**	21/**	5/n.s.W	4/n.s.	11/**	14/*		
Olanna	7.0 ± 0.3	6.8 ± 0.2	2.7 ± 0.1		13.7 ± 0.1	15.7 ± 0.0		13.1 ± 0.1
n/p	11/**	8/**	6/**S		21/**	3/*		22/**
Weyiouanna	7.0 ± 0.3	7.6 ± 0.2			12.8 ± 0.4	15.4 ± 0.1		
n/p	7/**	7/**			8/**	9/*		
WAC	8.0 ± 0.4	9.1 ± 0.5	1.9 ± 0.1	13.1 ± 0.1	12.4 ± 0.2	15.4 ± 0.0	5.2 ± 0.5	
n/p	9/**	8/**	9/n.s.W	7/n.s.	6/**	6/*	3/	
LARS	5.9 ± 0.2	6.9 ± 0.3						
n/p	21/**	16/**						

Table 4.3 $\delta^{15}N$ signatures of feces and tissue from reindeer on five ranges on the Seward Peninsula, Western Arctic caribou (WAC) and captive reindeer and caribou. Means ± S.E. W = winter. S = summer. AC = antler core, AP = antler periosteum, RBC = red blood cells. Comparison of column means; * $p < 0.05$; ** $p < 0.01$; n.s. = not significant.

	δ^{15} Nitrogen							
	Winter sample							Summer
Range	AC	AP	Fecal	Muscle	Serum	RBC	Urine	Semm
Davis	-0.6 ± 0.2	0.3 ± 0.1	-1.7 ± 0.2		1.2 ± 0.2			-0.5 ± 0.1
n/p	14/**	11/**	14/**S		8/**			6/**
Gray	0.5 ± 0.1	0.7 ± 0.2	-0.6 ± 0.1		1.4 ± 0.1			1.0 ± 0.2
n/p	13/**	5/**	7/**S		11/**			13/**
Noyakuk	1.01 ± 0.2	2.5 ± 0.2	-1.0 ± 0.1	3.1 ± 0.1	2.1 ± 0.1	1.9 ± 0.1		
n/p	21/**	21/**	4/n.s.W	4/**	11/**	14/**		
Olanna	1.9 ± 0.2	3.3 ± 0.2	-0.02 ± 0.3		2.4 ± 0.1	2.2 ± 0.1		1.4 ± 0.1
n/p	11/**	8/**	6/**S		21/**	3/**		22/**
Weyiouanna	2.4 ± 0.2	3.0 ± 0.3			2.1 ± 0.2	2.3 ± 0.1		
n/p	7/**	7/**			7/**	9/**		
WAC	1.0 ± 0.2	1.6 ± 0.2	-0.8 ± 0.2	2.0 ± 0.2	1.9 ± 0.2	1.5 ± 0.1	-3.1 ± 0.8	
n/p	9/**	8/**	9/n.s.W	9/**	6/**	6/**	3/	
LARS	5.7 ± 0.1	5.8 ± 0.1						
n/p	21/**	16/**						

Table 4.4 Calf weights standardized to June 25th date for herds across the Seward Peninsula. Means ± S.E.

Davis		Gray		Noyakuk		Olanna		Weyiouanna	
1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
27.5 ± 0.1	27.6 ± 0.2	34.0 ± 0.2	34.0 ± 0.4	32.4 ± 0.3	31.9 ± 0.5	31.4 ± 0.3	32.7± 0.6	31.4 ± 0.3	32.6 ± 0.3
n = 451	n = 361	n = 371	n = 156	n = 393	n = 62	n = 180	n =150	n = 411	n = 236

CHAPTER 5

Climatic drivers of interannual variation of body weight, growth and reproduction in Alaskan reindeer

Abstract

Climate change at higher latitudes is expected to be reflected in annual temperature and precipitation patterns. These changes are likely to affect characteristics of the winter snow pack, timing of snowmelt, and emergence and maturation of plants. In turn, these changes will influence the energetic costs of foraging for northern herbivores and the concentration of nutrients and fiber in forage, thereby influencing the body weight, rate of growth and reproductive potential of grazing animals. I investigated the effects of snow depth, winter wind and spring and summer temperature patterns on production and population dynamics of reindeer on the Seward Peninsula, Alaska. Winter severity increases energetic costs of cratering through deep, dense snow, and spring and summer temperature influences the availability and nutritional characteristics of forage plants. These factors, in turn, influence the nutritional status of parturient and lactating females and growth of female calves with consequences for future reproduction. Weather variables were weakly correlated with June body weight of adult females. Unlike animals from most reindeer and caribou herds, female reindeer on the Seward Peninsula often breed as 5-month old calves but the proportion is variable from year to year with up to 50% of yearlings lactating in some herds. June body weight, growth of female calves and their subsequent reproduction were negatively correlated with winter severity, and summer temperature and positively correlated with spring temperature. I used Nome

weather data collected from 1987-1997 to model the effects of these variables on reproduction of yearling female reindeer. The model was significant ($p < 0.01$) and suggests that age of female reindeer and the *patterns* of temperature and precipitation caused by climate change in this region will be important to production and population dynamics of reindeer, rather than overall amplitude of climate change.

Key words: nutrition, climate change, winter severity, snow, temperature, primiparity, population dynamics, arctic, *Rangifer tarandus.*

Introduction

Northern vegetation and animal populations respond to pattern and amplitude of weather variables that may be changing in reaction to climate change (Post and Forchhammer, 2002). Although there are correlations between large scale changes in climate and plant and animal productivity (Griffith *et al.*, 2002), it is yet unclear what specific underlying mechanisms drive these responses (Foster 1989; Myneni *et al.*, 1997; Putman *et al.*, 1996; Saether, 1997; Post, and Stenseth, 1999; Post and Forchhammer, 2002). The interaction of climate and *Rangifer* populations in the North is of particular interest because of their ubiquitous circumpolar distribution and their importance to humans for both subsistence and commercial use (Brotton and Wall, 1997; Turi, 1998). Approximately, 17,000 reindeer exist in Alaska with the majority found on the Seward Peninsula. Reindeer are owned and extensively herded over large areas with meat and by-products sold to local and national markets (Finstad *et al.*, 2007).

Annual animal productivity is likely not influenced by a single seasonal or individual weather event but instead by the interaction of a suite of environmental factors that influence a number of physiological functions. Temperature, snow-fall, rain-on-snow events and wind alter accumulation, texture and density of snow which have been suggested as influencing the growth, reproduction and survival of *Rangifer* (Caughley and Gunn, 1993; Langvatn *et al.*, 1996; Weladji and Holand, 2003; Kumpula and Colpaert, 2003; Putkonen and Roe, 2003; Kohler and Aanes, 2004). Winter weather influences body mass of female reindeer (Skogland, 1983), birth weight (Skogland, 1984), and growth of calves (Weladji and Holand, 2003) because the timing,

accumulation and characteristics of snow influence the energy and protein balance during winter (Fancy and White, 1985; Gerhart *et al.*, 1996; Adamczewski et al., 1988; Parker *et al.*, 1984; Klein, 1999). Post and Stenseth, (1999) reported a negative relationship of ungulate calf mass and female fecundity with warm, wet winters. Also, during years of high snow fall, caribou calves exhibit lower weight gain and reduced reproduction (Adams and Dale, 1998). Severe winter weather may have long term effects on population growth as well, because young animals may be more sensitive to environmental variation than adults (Gaillard *et al.*, 1998) with lasting effects on early growth (Solberg *et al.*, 2004) and future reproduction.

The availability and quality of forage during the short summer growing season is an important factor influencing growth and deposition of body reserves for reindeer (Klein, 1964; Mitchell *et al.*, 1976). Environmental patterns during spring and summer affect the timing of growth events, both within and among plant species that ultimately influence the nutritional characteristics of forage at any given time (Hay and Heide, 1984; Hill *et al.*, 1995; Chapin *et al.*, 1980a; Chapin, 1983; Larigauderie and Kummmerow, 1991; Van Soest, 1994; Galen and Stanton, 1995). The timing of snowmelt has been found to have considerable influence on emergence of forage plants (Langvatn *et al.*, 1996, Post and Klein, 1999). A warmer spring and early snowmelt advances the emergence of *Eriophorum vaginatum* flowers and provides an earlier burst of digestible energy for reindeer on the Seward Peninsula (Cebrian *et al.*, 2008).

The proportion of nutrients and dietary fiber has a great influence on quality of forage. Fiber and protein concentrations fluctuate throughout the growing season because

the environment influences the ratio of cell contents to cell wall. Temperature has a great influence on the movement of nutrients within plants and fiber formation. Heat accumulation expressed as growing-degree-days (GDD) has been shown to be a good predictor of plant phenology and forage quality (Steyn *et al.*, 1996; Hill *et al.*, 1995; Van Soest, 1994, Finstad and Kielland, 2008). Tundra plants translocate a large proportion of their nutrient pool into newly forming leaves the first three weeks after snowmelt (Chapin *et al.*, 1980a). An increase in heat accumulation during spring will initiate earlier translocation of reserves to support leaf emergence which effectively increases the length of the growing season (Galen and Stanton, 1995; Hay and Heide 1984; Myneni *et al.*, 1997), which in turn has a positive influence on animal production (Albon *et al.*, 1992; Langvatan *et al.*, 1996). However, warmer temperatures later in the growing season initiate translocation of cell contents out of foliar tissue and increases fiber concentration in forage plants (Deinum 1984, Bennett and Mathias 1984) depressing digestibility (Van Soest, 1994). Finstad and Kielland (2008) found that emergence and fiber and nutrient concentrations of forage plants found on the Seward Peninsula, Alaska were positively correlated with heat accumulation patterns during spring, whereas nutrient concentrations were negatively correlated with heat accumulation patterns during summer.

Comparatively small differences in the proportion of these components can markedly influence weight gain and the nutritional status of reindeer (McEwan and Whitehead, 1970; Reimers, 1997; White 1983). Because the nutritional status of females during the breeding season influences conception rates (Dauphine, 1976; Ropstad *et al.*, 1991; Lenvik *et al*, 1988), birth weight (Skogland 1984), birth weight of subsequent

offspring (Lenvik *et al.*, 1988; Weladjii *et al.*, 2002) as well as onset of first reproduction (Albon *et al.*, 1987; Langvatn *et. al.*, 1996; Prichard *et. al.*, 1999), there exists a potential relationship between regional weather events, reproductive success, and population growth in *Rangifer* (Festa-Bianchet *et al.*, 1995; Reimers, 1983a,b; 1997; Weladji and Holand, 2003).

Reindeer on the Seward Peninsula provide an excellent model to test the effects of weather patterns on animal productivity for a number of reasons. Firstly, detailed historical weather data is available for Nome, Alaska, the site of the present study. Secondly, reindeer on the Seward Peninsula remain within a relatively small range year round reducing inter-annual variability in grazing conditions due to changing migration patterns (Oleson, 2005; Finstad *et al.*, 2007). Thirdly, individual reindeer in the herd near Nome are tagged and rounded up and handled annually making it possible to collect body weights and determine the lactational status of a large number of known age reindeer (Blodgett *et al.*, 1993). Lastly, female calves on the Seward Peninsula, Alaska exhibit rates of growth high enough during their first summer (Finstad and Prichard, 2000) that as many as 39 % conceive at 5 months of age (Prichard *et al.*, 1999). Calves that were heavier in January were more likely to be lactating in June, and lactating yearling females are heavier than non-lactating yearling females (Prichard *et al.*, 1999). So, unlike caribou which breed at two to three years of age, the proportion of lactating yearling reindeer will be determined by conditions during the time period after birth and before conception.

I hypothesize that annual weather variables on the Seward Peninsula will affect the growth rate, body weight and reproduction of female reindeer. I expect weather

events in winter to influence body condition of adult females and calf birth weight. I also expect weather conditions during April-June will affect early growth of calves, but weather conditions during summer will influence subsequent growth that collectively influences body weight in fall and reproduction in short yearlings.

Study Site

This study was conducted on the 3,875 km^2 Davis reindeer range (Fig. 5.1), located on the Seward Peninsula in the vicinity of Nome, Alaska (64°31'N latitude, 165°27'W longitude). The terrain consists of hills and mountains under 700 meters in elevation dissected by numerous river and creek drainages. Vegetation consists of tussock tundra in lower elevations, deciduous shrubs and forbs in drainages and mid slopes, and lichen mat on upper slopes. Overall lichen biomass of the range was estimated at 444 kg ha^{-1} and a maximum vascular plant biomass estimated at 866 kg ha^{-1} (Swanson *et al.*, 1985). The average January temperature is -15 °C, the average July temperature is 10.3 °C. Average precipitation is 422 mm per year. Two additional ungulates found in the study area are moose (*Alces alces*) and muskoxen (*Ovibos moschatus*) and predators include red foxes (*Vulpes vulpes*), brown bears (*Ursus arctos;* Chetkiewicz, 1993) and recently wolves *Canis lupus* (Oleson, 2005). Based on census records, the herd has increased in size from 4,000 in 1987, to approximately 8,000 animals in 1997, an increase in density of 1.0/km^2 to 2.0/km^2. Body weights remained high throughout the study period (Finstad and Prichard, 2000) suggesting that density dependent food limitation was not in effect.

Methods

National Weather Service mean daily temperature, snow-depth and wind velocity data for Nome, Alaska was acquired from the Natural Resource Conservation Service (NRCS), United States Department of Agriculture, Anchorage, Alaska for the years 1985-1997. An index of winter severity was calculated by the interaction of two weather variables; snow accumulation and windiness. This index was assumed to be proportional to the energy required for reindeer to crater through snow because increased wind velocity increases density of the re-deposited snow pack (Clagett, 1978). Snow accumulation was defined as the snow-cm-days (sum of daily snow-depth on the ground) for the entire winter (Nov. - April). Windiness during winter was calculated as the sum of the daily average wind speed, (cm s^{-1}), for days with snow on the ground. Winter severity (WSEV) was calculated as the sum of snow-cm-days times the $\log_{10}$ of the sum of wind-velocity-days.

$$\text{WSEV} = \sum(\text{snow depth cm d}^{-1}) * \log\sum(\text{avg. wind velocity m s}^{-1}\text{ d}^{-1}) \quad (5.1)$$

Growing-degree-days were calculated as the sum of the mean daily temperature for Nome, Alaska (average of maximum temperature and minimum temperature) above a standard (T_{base}) of 0° C for spring (May and June) and summer (July). Any temperature below T_{base} is set to T_{base} before calculating the average.

$$GDD = \sum \frac{T_{max} + T_{min}}{2} - T_{base} \quad (5.2)$$

Rate of warming (GDD day^{-1}) during the period that calf body weight data were collected was determined by the accumulation of heat (GDD) divided by the number of

days from the first handling date, approximately Julian date (JD) 159, to the last handling date in June.

$$\text{GDD d}^{-1} = \left(\sum_{i}^{n} GDD_i \right) \Big/ n, \tag{5.3}$$

where n is the number of days between first and last handling dates during the month of June.

All calves were weighed during the first handling and at each subsequent handling until the end of June and the handling means used to calculate mean daily gain (kg d^{-1}).

The relationship between GDD and chemistry of forage plants on the Seward Peninsula Alaska has been developed in another study (Finstad and Kielland, 2008). To estimate large-scale effects of temperature on vegetation across the Seward Peninsula, nitrogen and digestibility data was taken from Finstad and Kielland (2008) and pooled according to plant growth form (i.e., deciduous shrubs, graminoids, forbs) and non-linear regressions were performed using nitrogen concentration and digestibility as dependent variables with GDD as the independent variable.

Reindeer of the Davis herd forage year round near Nome with minimal influence by the herder and no supplemental feeding. In early June, reindeer herders locate and move groups of reindeer to a staging area near the handling facility, located approximately 8 km north of Nome, Alaska. Beginning mid June through early July, groups consisting of 500 to 2000 animals are segregated out from the main herd and moved into the handling facility for censusing, velvet antler harvest, castration, and veterinary care. All calves processed through the handling facility receive ear-tags with

unique identification numbers and weighed using a Tru-test™ livestock scale. Adult reindeer are moved through the facility and held in crushes (Finstad and Renecker, 1993) and data collected on the health of the animal, lactational status (the presence or absence of a distended udder in females; Bergerud 1964), and date of castration for males. Weights of yearling and adult females were collected using a crush mounted on a Tru-test™ livestock scale. Adult and yearling data presented were collected from 1987 to 1997 and calf weights were collected from 1991 to 1997.

Adult weights were evaluated using an Analysis of Variance (ANOVA) with year and lactational status as fixed effects. Pearson product coefficients of correlation were determined for mean adult female body weight during June 1987-1997 and weather variables of the preceding winter and spring. Mean female calf weights were determined for all handling dates for years data was collected, 1991-1997 (Systat 8.0, SPSS Inc., 1998). The average first handling date for all years occurred on Julian Date (JD) 159 and mean female calf body weight was treated as starting weight. Mean weights of calves during subsequent June handlings were used to determine rate of gain (kg/day) for that year by determining a general linear model (GLM Systat 8.0, SPSS Inc., 1998).

The annual proportion of lactating yearlings was estimated using a generalized linear model (GLM Systat 8.0, SPSS Inc., 1998) where the number of yearling females lactating in a year was assumed to be binomially distributed with the number of trials equal to the number of animals examined in a year. The independent variables were ln(WSEV) from September through May of the winter prior to birth of the yearlings, the sum of GDD for the previous May-June when the yearlings were calves, and the sum of

GDD for the previous July when the yearlings were calves. The parameters of the model were estimated using the SAS NLIN procedure (SAS NLIN procedure; SAS Institute, 1990).

Results

The temperature regime during spring and summer and snow accumulation and wind velocity during winter varied greatly throughout the 11-year study period (Table 5.1). May and June GDD varied from 500.5 in 1992 to 866.5 a year later. Winter severity [$\sum$ snow depth cm^{-d} * log($\sum$wind velocity m-s)] ranged from 9814 in 1992 to 15016 in 1989.

Nitrogen concentration and digestibility of Seward Peninsula forage plants were related to GDD throughout the growing season (Figs. 5.2–5). Nitrogen concentration and digestibility increased initially with spring warming followed by a decline until fall senescence (Figs. 5.2-5). The rate of decline in nitrogen concentration of willows during summer tended to increase at approximately 1000 GDD (Fig. 5.4).

Mean June body weights of adult female reindeer differed significantly among years and lactational status $p < 0.001$ (Table 5.1) with a minimum of 73.7 kg, $S_{\bar{x}} = 1.5$ during 1989 for lactating females to a maximum of 92.48 kg, $S_{\bar{x}} = 1.66$ for nonlactating females in 1994. Correlation coefficients suggest June body weight of nonlactating adult females was better correlated with spring warming ($R^2 = 0.55$), rather than lactating females ($R^2 = 0.47$). June body weight of lactating females is negatively correlated with

winter severity (R^2 = -0.14), whereas June body weight of nonlactating females is positively correlated with winter severity (R^2 = 0.12), (Table 5.2).

Calf growth rates (0.13 to 0.44 kg d^{-1}) were higher in years of increased spring warming (May/June GDD), p = 0.005; R^2 = 0.84 (Fig. 5.6). Mean weight of calves at first handling in June (Julian Date 159) varied from year to year and was predicted by severity of the winter preceding birth p = 0.009; R^2 = 0.77 (Fig. 5.7).

A total of 213 female yearling reindeer were observed and classified as lactating or not lactating based on presence or absence of a distended udder over the eleven-year period. The observed proportion, 1987-1997, ranged from 3.9% in 1993 to 39.0% in 1995, $\bar{x}$ = 16%. Lactating female yearlings tended to be heavier, ($\bar{x}$ = 63.8 kg, $S_{\bar{x}}$= 2.6) than non-lactating females ($\bar{x}$ = 57.1 kg, $S_{\bar{x}}$ = 0.57), (Fig. 5.8), (See Prichard *et al.*, 1999 for original data).

The model predicting proportion of yearling females lactating using three summer and winter variables was highly significant ($p < 0.001$) and the relationship between each of the three variables and lactation rates was highly significant ($p < 0.001$, all three variables), (Fig. 5.9). Severity of the winter prior to the birth and warmer Julys (JGDD) had a negative influence on yearling lactation rates (Fig. 5.9). Spring temperature (GDD in May and June) following birth had a positive effect on the proportion of yearlings lactating (Fig. 5.9). The estimated model was:

$$\text{Ln}(\pi / (1-\pi)) = 4.7654 + 0.0119*(\text{GDD May-June}) - 0.0178*(\text{GDD July}) - 0.521*\text{Ln}(\text{WSEV}) \quad (5.4)$$

where π is the proportion of yearlings lactating.

Discussion

I observed large annual variability in growth rate, body weight and reproductive rates among female reindeer on the Seward Peninsula (Tables 5.1-3; Fig. 5.8). The probability of reproduction in female reindeer is strongly correlated with body weight and/or fat reserves during the breeding season (Dauphine, 1976; Thomas, 1982; Reimers, 1983a; Cameron *et al.*, 1993; Gerhart, 1995; Gerhart *et al.*, 1997). Calf body weight and calf survival are both influenced by female weight in spring (Lenvik *et al.*, 1988). Because small changes in diet could have a profound effect on nutritional status of reindeer females (White, 1983), changes in forage quality and accessibility may induce large variations in body condition around conception thresholds. The data I present in this study suggest that much of this variation can be explained by the indirect and direct effects of weather on the Seward Peninsula grazing environment.

Inflorescences of cottongrass (*Eriophorum vaginatum*) are early spring sources of digestible energy for lactating reindeer females and calves. A warmer spring and earlier snowmelt will advance the emergence of cottongrass flowers and provide an earlier burst of digestible energy (Cebrian *et al.*, 2008; Finstad and Kielland, 2008). Plants adapted to cold climates generally require high tissue nitrogen concentrations as a prerequisite for high metabolic potential and rapid growth (Chapin, 1983). Deciduous shrubs, forbs, and graminoids translocate stored nitrogen to support rapid growth of green leaves in spring (Chapin *et al.*, 1980a; Chapin and Kedrowski, 1983; Shaver and Kummerow, 1992). Newly emerging shrubs and forbs on the Seward Peninsula contain very high

concentrations of nitrogen and minerals (Finstad and Kielland, 2008). Warm spring temperatures will initiate early leaf emergence (Tieszen, 1978; Deinum, 1984) which exposes stored plant nutrients to grazing by lactating reindeer females and calves. Protein intake is especially important for juvenile *Rangifer* because they preferentially deposit body protein over body fat, which directly influences growth and conception rates (McEwan and Whitehead, 1970; White, 1983; Allaye-Chan, 1991; Ropstad *et al.*, 1991). Reindeer calves in Alaska begin to consume forage shortly after birth (RRP unpublished data; http://reindeer.salrm.uaf.edu) so earlier availability and increased nitrogen and mineral concentrations in forage should support increased growth rates. Calf growth rates on the Seward Peninsula were higher in years with warm springs (Fig. 5.6) followed by an increase in yearling lactation rates the following year (Fig. 5.8) suggesting that earlier snowmelt and leaf emergence had a positive influence on reindeer productivity.

Although newly emerged leaves of graminoids and shrubs are high quality forage they do not reach a nutritional peak until several weeks later in spring. Finstad and Kielland (2008) have demonstrated this relationship is well predicted by GDD on the Seward Peninsula (Figs 5.2-5). Nitrogen concentration and digestibility of sedges and digestibility of willows, preferred reindeer forage, increased rapidly during spring until they reached a peak in mid June (Figs. 5.2-4). Warmer spring temperature across the Seward Peninsula will tend to accelerate the increase in nutrient concentration and digestibility. Recruitment rates of Seward Peninsula reindeer can exceed 80% in some years (unpublished data, Reindeer Research Program; http://reindeer.salrm.uaf.edu) and growth rate potential is high (Finstad and Prichard, 2000) so an increase in warming

proceeding snowmelt with its positive affect on forage quality would likely increase the production of reindeer herds with all other factors held equal.

Also, the degree of synchrony in emergence of plants during spring is a result of temperature (Bliss, 1962) and topography (Nellemann and Thomsen, 1994). Higher spring temperatures are expected to increase the variability in snowmelt patterns (Price and Waser, 1998; Post and Stenseth, 1999). Areas with shallow snow will emerge proportionately earlier than areas of heavy snow creating a longer period of early emergent high quality forage. Earlier availability and increased patchiness of high quality forage during spring may provide improved nutrition of calves with a corresponding increase in growth rate (Albon and Langvatn, 1992) and conception rates the following autumn (Cameron *et al.*, 1993).

Growing-degree-days in July have the opposite (negative) effect on yearling lactation compared to the positive but non significant ($p = 0.08$) effect May-June GDD has on weight and lactation rate (Fig. 5.8). Movement of nitrogen out of foliar tissue begins as leaves mature (Fig. 5.5) most likely to support root growth after the ground thaws (Chapin and Kedrowski, 1983; Chapin, *et al.*, 1980a; Shaver and Kummerow, 1992). Warm July temperatures accelerate maturation of foliar tissue (Hay and Heide, 1984; Hill *et al.*, 1995), and thawing of frozen soil which in turn accelerates movement of nutrients out of leaves to storage organs or roots (Finstad and Kielland, 2008).

Furthermore, an increase in summer temperature promotes greater biomass production of leaves with a pronounced decline in nitrogen concentrations due to growth dilution (Chapin *et al.*, 1980b; Laine and Henttonen, 1987; Albon and Langvatn, 1992).

Cool weather during the summer months may both retard nutrient retranslocation to belowground tissue and slow the rate of dilution of nutrients with increased biomass thus, maintaining forage quality (Van Soest, 1994). Also, higher summer temperatures tend to reduce digestibility of forage plants (Figs. 5.4-5) by accelerating formation of lignin (Deinum, 1984; Van Soest, 1994). Warmer temperatures during summer may also promote the formation of digestibility-inhibiting compounds other than lignin. Leaves of plants growing at elevated summer temperatures produce more tannins which further reduces their palatability and digestibility (Dury *et al.*, 1998). These observations suggest that forage quality in mid to late summer is inversely related to GDD. Warmer summers will lower the ratio of cell contents to cell wall and increase lignification of forage plants across the Seward Peninsula (Finstad and Kielland, 2008). Productivity of reindeer herds will likely drop as a result because lower diet quality will influence protein deposition and fattening in females (Langvatn *et al.*, 1996).

Environmental factors during winter including snowfall, wind, and rain-on-snow events will influence the depth and density of the snowpack. Reindeer that expend considerably more energy to access snow covered forage (Fancy and White, 1985) will have to mobilize fat stores resulting in lower spring body weights and smaller calves (Rognmo *et al.* 1983; Allaye-Chan, 1991; Parker *et al.*, 1984). Female weight in spring also strongly influences production of milk during early lactation and subsequent calf growth (White and Luick, 1984; White, 1992). Increased snow accumulation will not only reduce the quantity of forage available but may force lactating females and calves to feed in areas of lower forage availability (Adamczewski *et al.*, 1988). Increased snow

accumulation may also delay snowmelt, which significantly delays emergence of forage plants and limits energy availability to lactating females and calves (Adamczewski *et al*, 1988, Cebrian *et al.*, 2008). Redeposition of snow due to wind has a direct effect on density of the snowpack. Particle size of airborne snow decreases with increasing wind speed and is deposited in a fine-grained, dense matrix. Winters with high snow accumulation and increased wind will convert the snowpack into a deep dense barrier covering ground vegetation which will increase the energy expenditure of cratering reindeer (Clagett, 1978).

These data suggest a relationship between winter severity, reproductive status and adult female body weight during spring (Tables 5.1-2). In all but one year non-lactating females were heavier in June than lactating females (Table 5.1). Adult female reindeer will enter late spring with body reserves that will either be allocated largely to maintenance of body weight if without a calf or to milk production if with a calf. Because reindeer calves in Alaska are generally born in April, females will likely drain most body reserves for the production of high energy milk before they are weighed in June (Reimers *et al.*, 1983a, b; Chetkeiwitz, 1993). Thus, effects of winter severity will most likely be reflected in differences in milk production and calf growth in lactating females, but in body weight of non-lactating females. June body weight of non-lactating adult females was better correlated with spring warming ($R^2 = 0.55$), than lactating females ($R^2 = 0.47$). June body weight of lactating females was negatively correlated with winter severity ($R^2 = -0.14$), whereas June body weight of nonlactating females was positively correlated with winter severity ($R^2 = 0.12$), (Table 5.2). Early June calf weights (Fig 5.7) were lower

following severe winters, suggesting calf birth weights and/or early growth rate were influenced by the body weight of parturient females coming into spring as well as milk production immediately after birth (Skogland, 1983; Skogland, 1984; Weladji and Holand 2003). Unfavorable snow conditions that limit forage availability may become critical for calving success, which is affected by nutritional status of females during late gestation (Cameron *et al.*, 1993). Winter severity prior to birth has a strong negative influence on yearling lactation rates as indicated by the model (Fig. 5.9). The model suggests that severe winters with followed by a cold and delayed spring and a hot summer show the greatest negative influence on reproductive rates of female yearling reindeer.

Although spring and summer GDD have opposing effects on reproduction in the model the two variables may be tightly coupled in real world climate. I regressed Nome July GDD against May/June GDD for the years 1950 to 2006 and plotted the residuals (Fig. 5.10). These data show the variables are related but the degree to which they are coupled is variable from year to year. Some years spring temperatures are relatively cooler than in summer (points above regression line), while some years spring is warmer than summer (points below regression line), thus there is a variable degree of decoupling of seasonal GDD from year to year. It is interesting to note that the plot suggests a 50 year oscillation in the coupling of spring and summer GDD and that the amplitude of decoupling has lessened since the mid 1980's (Fig. 5.10).

Increased insect harassment during warm summers also affects productivity in some caribou and reindeer herds (Helle and Kojola, 1984; Mörschel and Klein, 1997;

Mörschel 1999; Russell *et al.*, 1993). Increased insect harassment can decrease the time spent feeding and increase the time spent moving and standing (Mörschel and Klein, 1997). Beginning in 1986 all reindeer in the study and adjacent herds were annually treated with the drug Ivomec® which significantly reduces infestation of warble fly larvae (*Oestridae*) (Dieterich and Morton, 1990). Treatment of the study herd ended after 1992. Increased numbers of emerging warble fly larvae have been observed on reindeer during June handlings since treatments were halted (G. Finstad, pers. observ.). Intensity of oestrid fly harassment during the summers of 1993-1997 likely increased, but had no apparent effect on yearling lactation rates (Fig. 5.9). Treatment with Ivomec®, however, does not affect mosquito populations.

Whereas the results of this study suggest that female weight, growth and reproductive rates were largely influenced by winter severity and temperatures during the growing season, I recognize that additional factors may be important over a longer time scale. Changes in stocking density, plant species composition, predation rates, or lichen availability could add additional variation to the system potentially masking effects of weather patterns.

In conclusion, stochastic annual weather patterns appear to influence the grazing characteristics of the Seward Peninsula with growth and reproductive consequences for reindeer. First, snow and wind interact to form a cap over winter forage. The depth and density of this cap affects the energy expended to access forage, diminishing body condition of parturient females. Body condition of females indirectly affects calf birth weight and maternal investment in early calf growth with consequences on future

reproduction. Second, increased temperature during spring should have a positive influence on nutritional status of lactating females and calf growth. Warmer springs will initiatie earlier plant emergence and accelerate the movement of nutrients to aboveground plant tissue. Also, earlier spring green-up could prolong the availability of high quality forage by creating a patchwork of vegetation communities with varying phenological stages of growth. In contrast, increased temperature later in summer negatively influence growth and reproductive rates of reindeer by lowering levels of digestible nutrients in forage plants through a combination of translocation, growth dilution and increases in structural/defensive compounds (Langvatn et al., 1996; Weladji et al., 2002; Finstad and Kielland, 2008)

Usually the impact of annual weather events on reindeer populations was difficult to predict because conditions vary from year to year and have dichotomous effects on nutritional status and subsequent reproduction. However, we now may be capable of predicting the effects of climate change on reindeer production because long term averages of weather variables are expected to ramp up or down. Reindeer producers can use the predictions of this model to adjust stocking densities from year to year because the results of this study strongly suggest that cumulative effects of weather variables will influence the trajectory of reindeer production. The negative effect of severe climate on reindeer production is ameliorated by lower population densities (Weladji *et al.*, 2002). If winter and summer weather patterns predict animals will enter the following winter in lesser body condition (as indicated by lower reproduction in the model) then more animals can be sent to slaughter; thereby minimizing the effect of winter loss on overall

economic output. Reindeer producers in Alaska now may manage their herds adaptively rather than reactionary to climate change.

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Figures

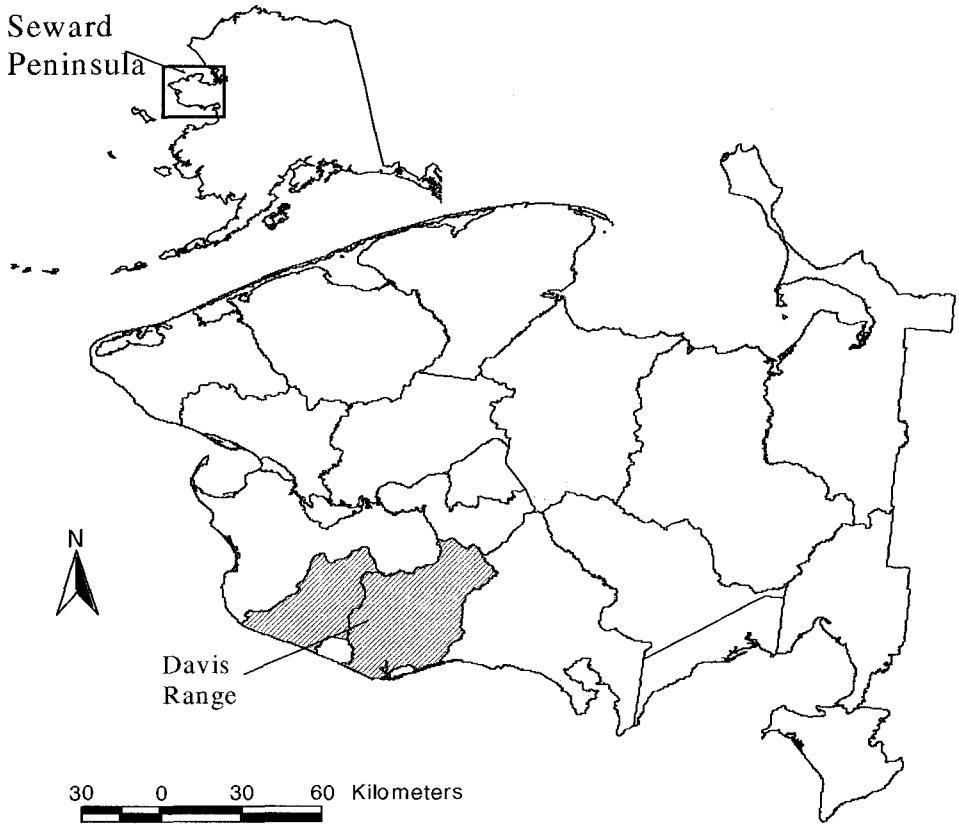


Figure 5.1 Davis reindeer range on the Seward Peninsula, AK.

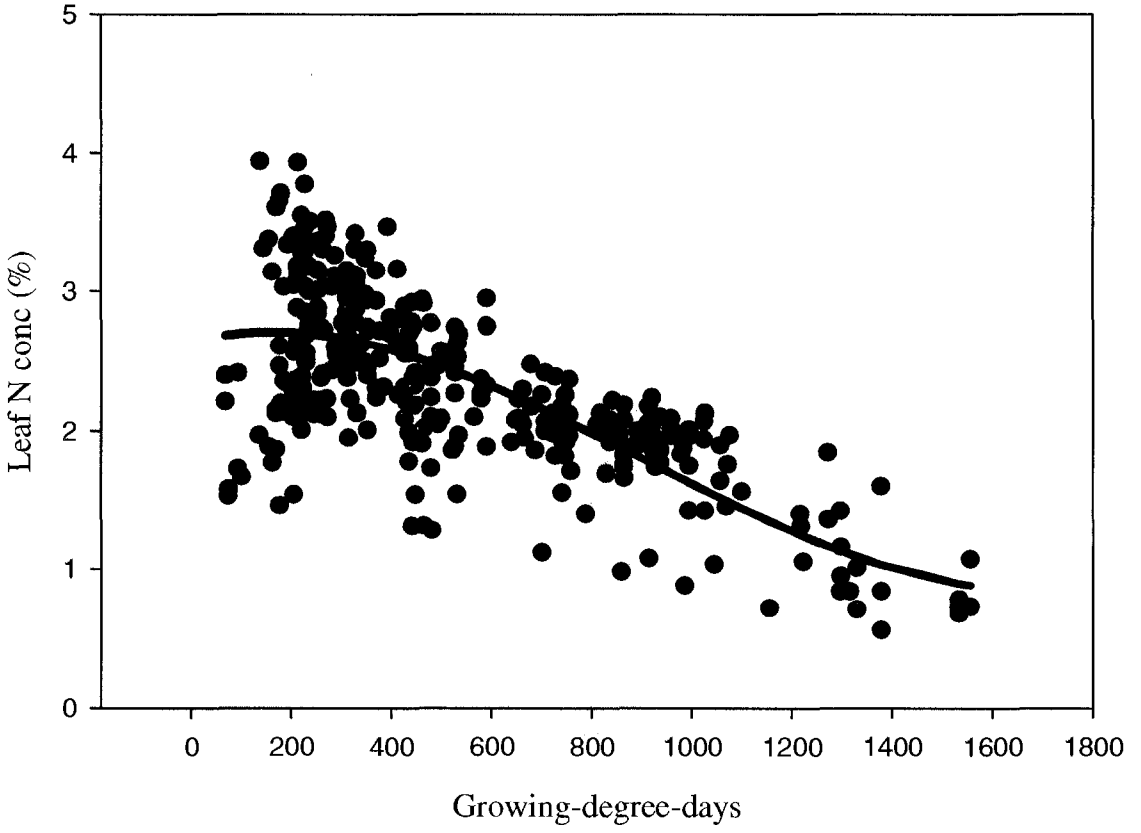


Figure 5.2 Nitrogen concentrations of Seward Peninsula sedges in relation to growing degree days (GDD); (*Carex aquatilis, Carex bigelowii , Carex lyngbyaei, Eriophorum angustifolium*) during the growing season. $N(\%) = 2.6 + 0.00087(GDD) - 0.3E\text{-}5(GDD^2) + 0.8E\text{-}7(GDD^3)$.
$N = 354$, $p < 0.0001$, $R^2 = 0.52$

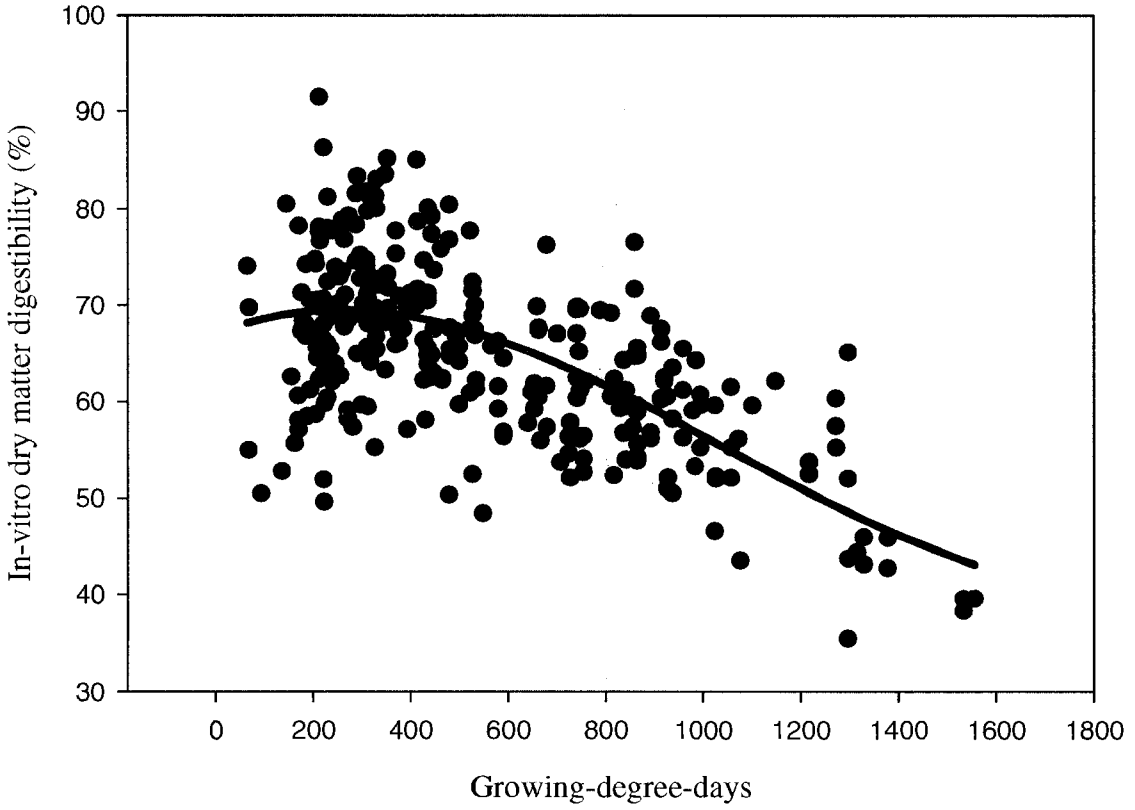


Figure 5.3 IVDMD (%) for the major sedges found in Seward Peninsula reindeer diet
Data are pooled for the major sedges found in Seward Peninsula reindeer diets; (*Carex aquatilis, Carex bigelowii , Carex lyngbyaei, Eriophorum angustifolium*) during the growing season.
IVDMD (%) = 67.0 + 0.02(GDD) – 4.5E-5(GDD^2) + 1.4E-8(GDD^3)
N = 302, $p < 0.0001$, $R^2 = 0.42$

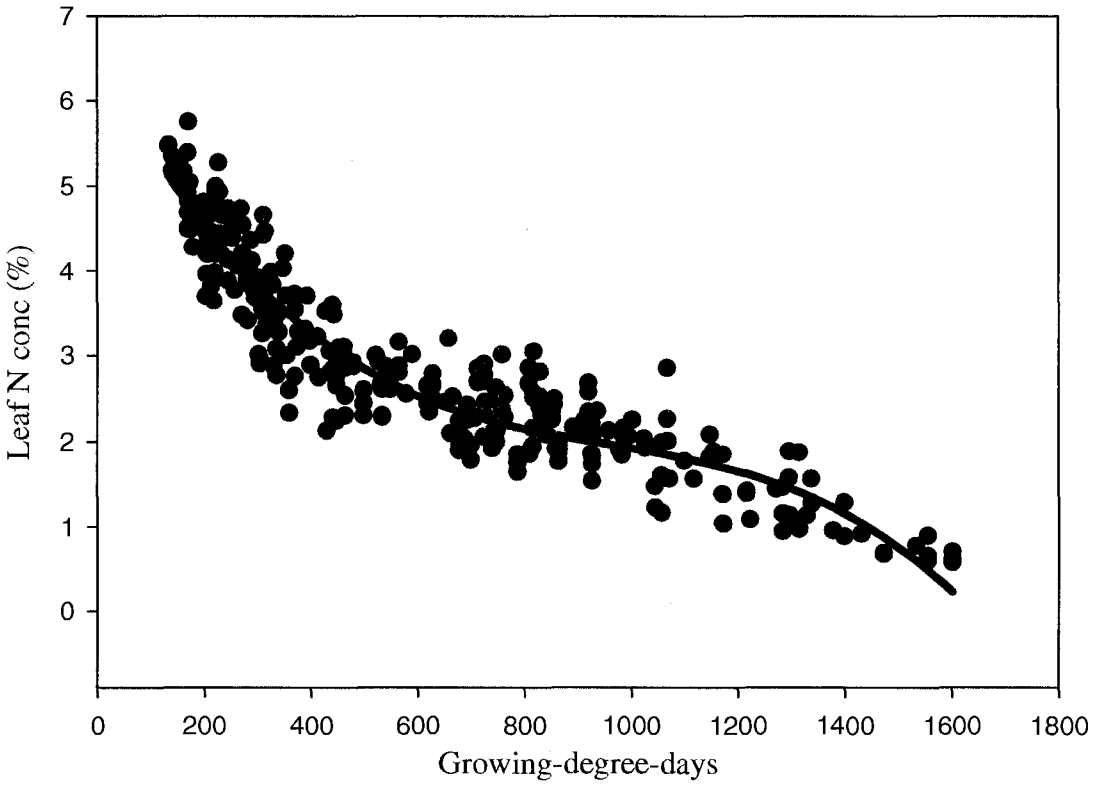


Figure 5.4 Nitrogen concentrations of Seward Peninsula willows in relation to growing degree days (GDD); (*Salix pulchra* , *Salix alexsensis, Salix lanata,* and *Salix fuscescens*) during the growing season.
$N(\%) = 6.6 - 0.012(GDD) + 1.2E\text{-}5(GDD^2) - 0.4E\text{-}8(GDD^3)$
$N = 354,\ p < 0.0001,\ R^2 = 0.90$

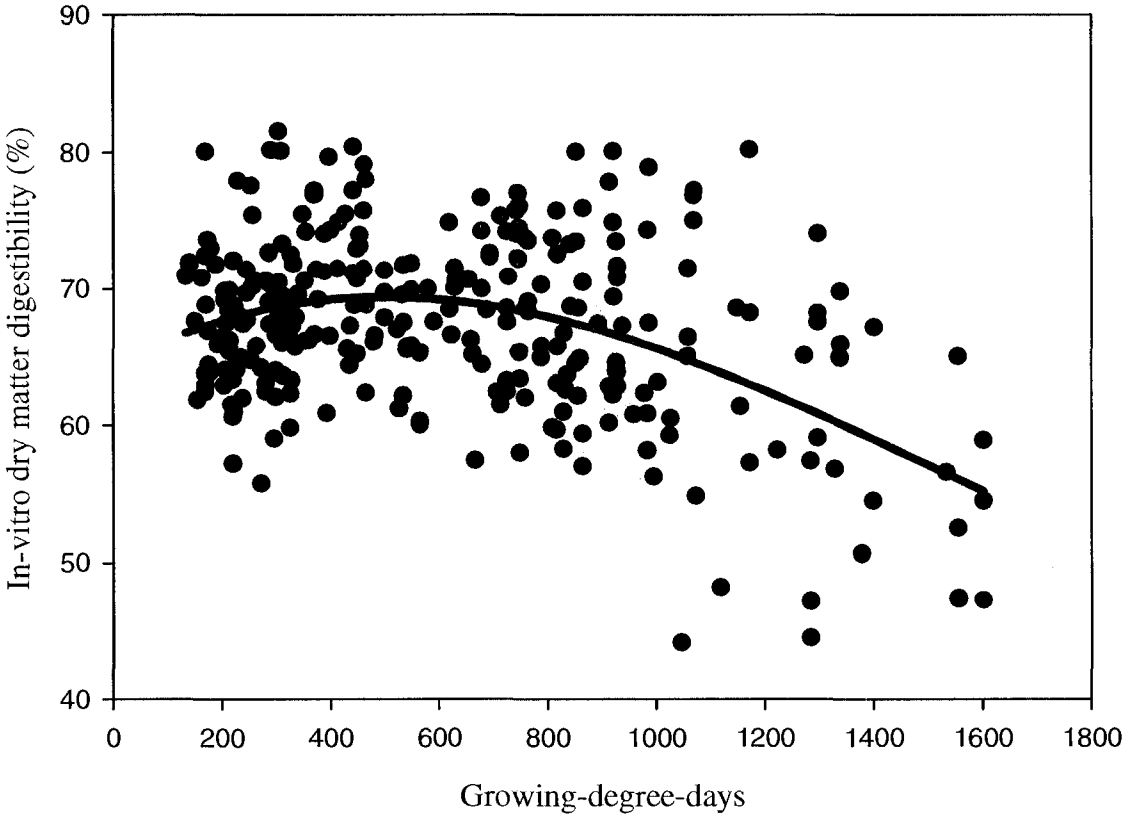


Figure 5.5 IVDMD (%) for the major willows in Seward Peninsula reindeer diets. Data are pooled for the major willows in Seward Peninsula reindeer diets; (*Salix pulchra* , *Salix alexsensis, Salix lanata,* and *Salix fuscences*) during the growing season.
IVDMD (%) = 66.7 + 0.9E-2(GDD) – 0.7E-5(GDD^2) - 0.6E-8(GDD^3)
N = 301, $p < 0.001$, $R^2 = 0.19$.

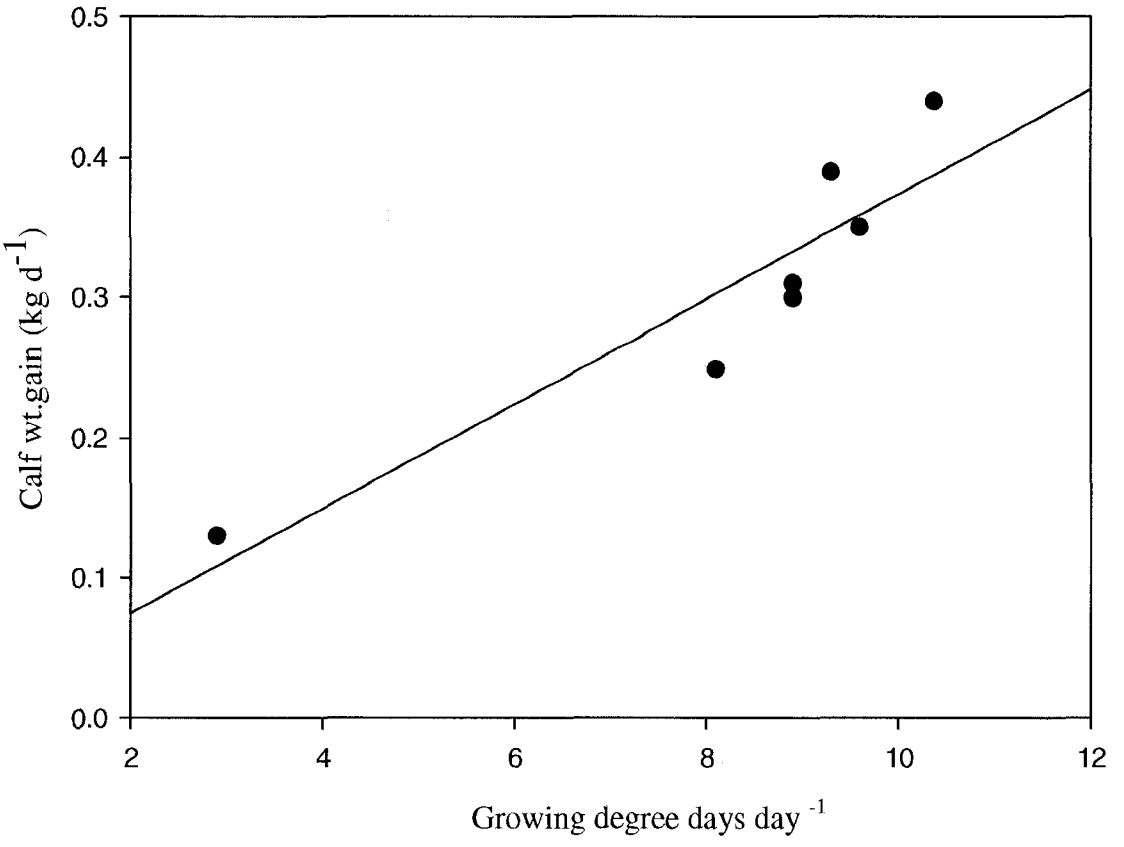


Figure 5.6 Relationship between growth rate of Davis female reindeer calves (kg d^{-1}) and rate of warming (GDD d^{-1}) during June of years 1991-1997 on the Seward Peninsula, Alaska. GDD $d^{-1} = \left(\sum_{i}^{n} GDD_i\right) / n$ for the month of June; where n is the number of days between first and last handling dates during the month of June.
Growth (kg d^{-1}) = - 0.00009 + 0.037 (GDD d^{-1}), p = 0.003, R^2 = 0.85.

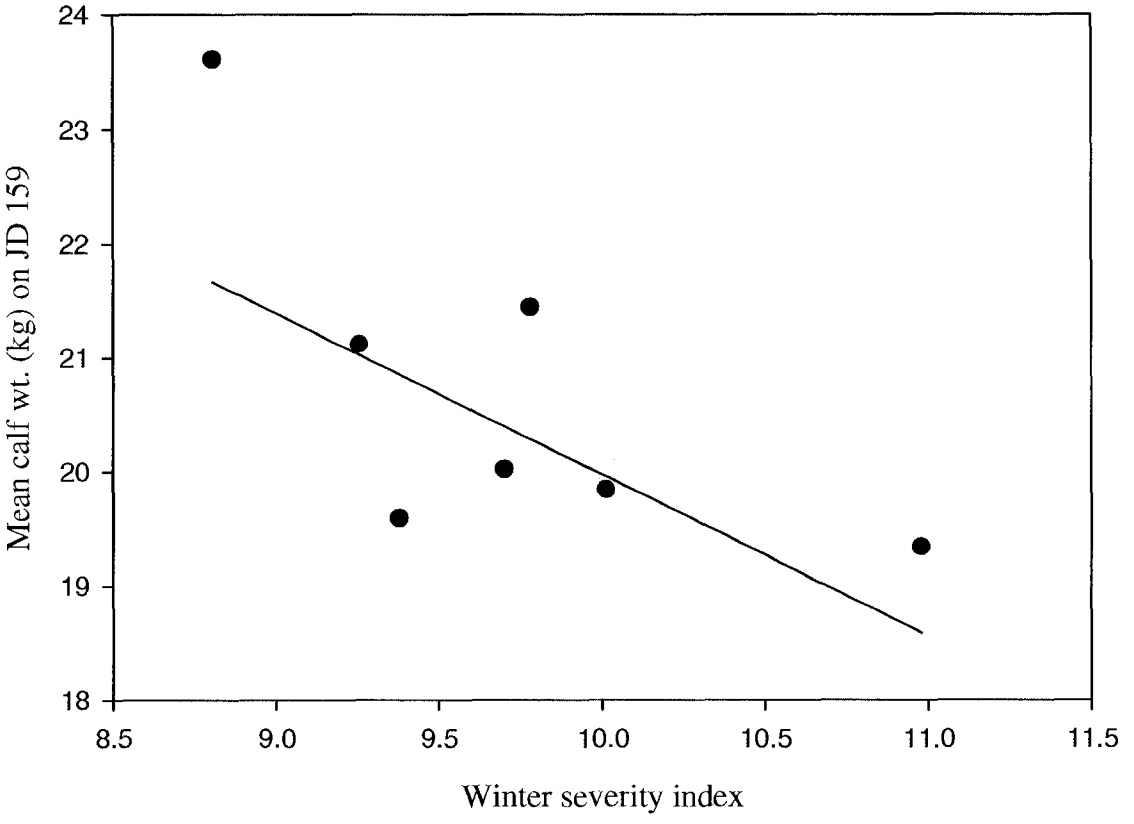


Figure 5.7 Relationship between mean female calf weight (kg) on Julian date 159 and winter severity index (WSEV); $\sum$(snow depth cm d^{-1}) * log$\sum$ (wind velocity m s^{-1}) of winter preceding birth.
Mean calf wt. = 35.7 - 1.5(WSEV). N = 7, p = 0.08, R^2 = 0.50.

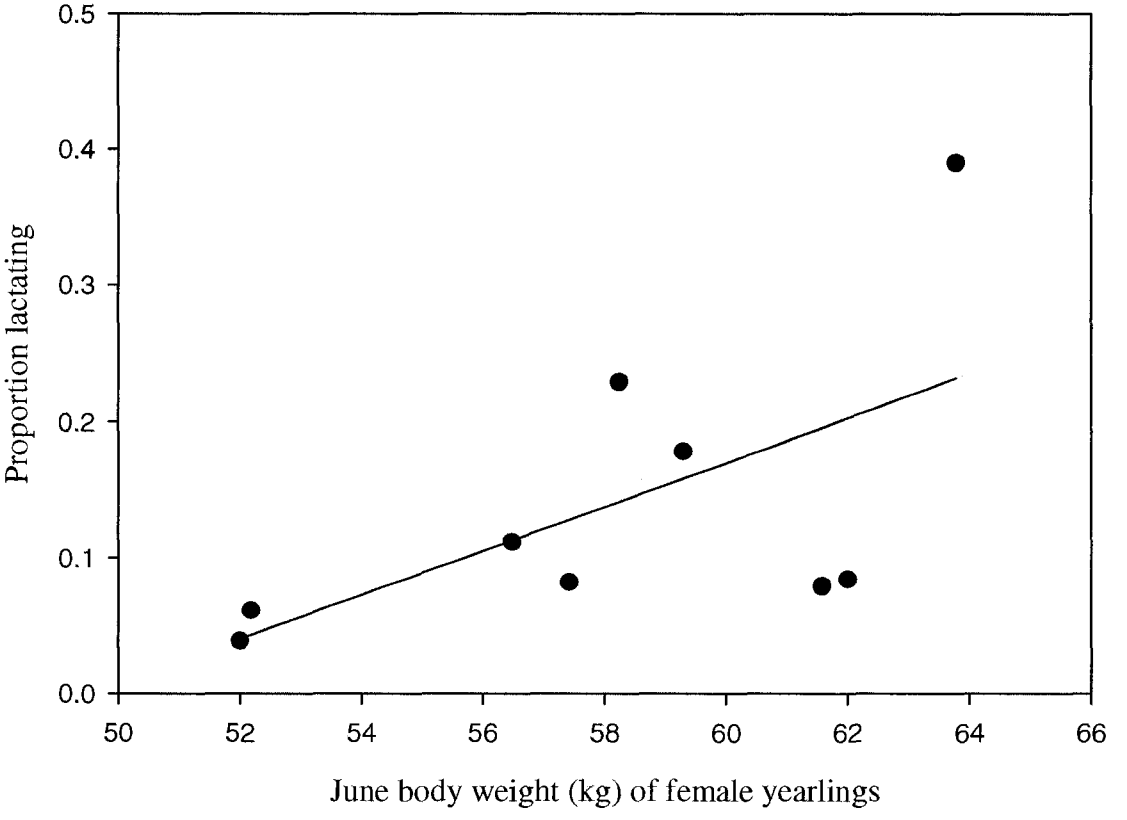


Figure 5.8 Relationship between the proportion of lactating yearling reindeer and mean June body weight (kg).
Proportion lactating = -0.81 + 0.016(Wt.). N = 9, p = 0.085, R^2 = 0.36

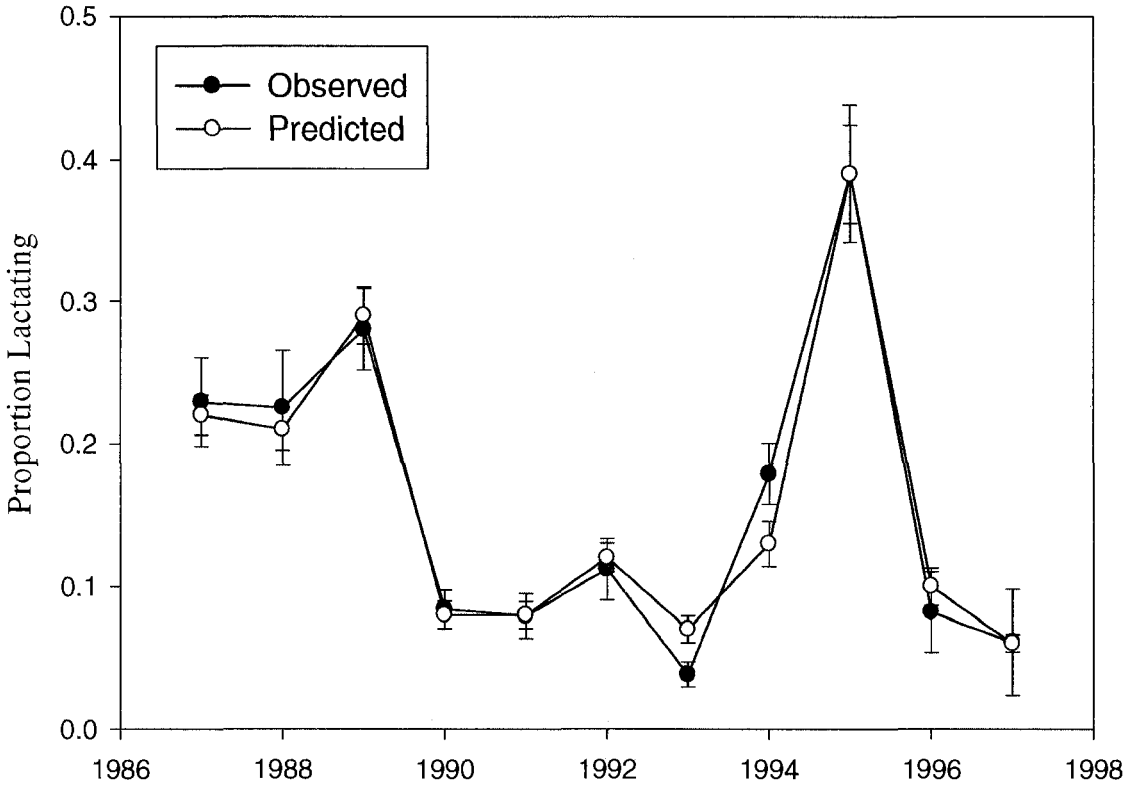


Figure 5.9 Predicted and observed lactation rates (SE) for yearling reindeer on the Seward Peninsula. The predicted lactation rate is based on the equation:
$\text{Ln}(\pi / (1-\pi)) = 4.7654 + 0.0119*(\text{GDD May-June}) - 0.0178*(\text{GDD July}) - 0.521*\text{Ln}(\text{WSEV})$
where π is the lactation rate.

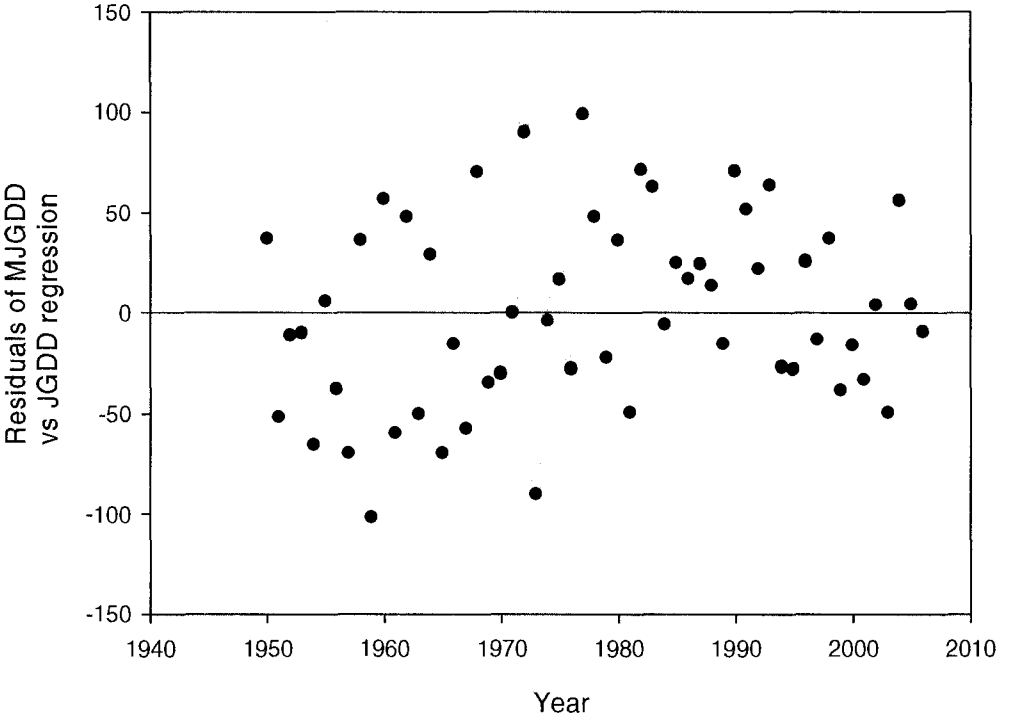


Figure 5.10 Regression residuals (GDD) of spring (May and June) growing degree days (MJGDD) predicting summer (July) growing degree days (JGDD) for Nome, Alaska in the years 1950 - 2006. Regression equation: JGDD = 280.2 + 0.15(MJGDD). $p = 0.05$, $R^2 = 0.7$.

Tables

Table 5.1 June body weight of 3 year or older, lactating and nonlactating female reindeer (mean and S.E.), heat accumulation during May and June (MJGDD), heat accumulation during July (JGDD), and natural logarithm of the winter severity index (WSEV) of winter prior to June weighing.

Year	1987	1987	1988	1988	1989	1989	1990	1990	1991	1991	1992	1992
$\bar{x}$	77.50	77.20	79.80	86.90	73.70	79.90	86.60	88.90	82.46	84.97	77.43	85.03
SEM	0.94	1.93	1.14	1.87	1.50	1.70	1.01	1.76	0.90	1.37	0.89	1.17
Lact	+	-	+	-	+	-	+	-	+	-	+	-
N	87	20	84	37	32	29	122	28	85	35	106	73
MJGDD	381.7	381.7	456.9	456.9	279.7	279.7	408.1	408.1	434.7	434.7	278.1	278.1
JGDD	361.4	361.4	361.7	361.7	305.8	305.8	411.7	411.7	396.7	396.7	343.6	343.6
LNWSEV	8.09	8.09	8.92	8.92	9.92	9.92	8.9	8.9	9.38	9.38	8.81	8.81

Year	1993	1993	1994	1994	1995	1995	1996	1996	1997	1997
$\bar{x}$	77.82	92.64	85.69	92.48	81.50	85.23	78.99	86.75	74.69	81.00
SEM	2.11	5.13	1.10	1.66	1.83	3.68	1.22	2.81	1.01	1.55
Lact	+	-	+	-	+	-	+	-	+	-
N	22	7	64	20	8	13	55	16	54	27
MJGDD	481.4	481.4	481.4	481.4	351.9	351.9	322.5	322.5	412.50	412.50
JGDD	415.6	415.6	319.4	319.4	304.4	304.4	353.9	353.9	328.33	328.33
LNWSEV	9.7	9.7	9.26	9.26	10.98	10.98	9.78	9.78	10.01	10.01

Table 5.2 Pearson correlation matrix (R^2) of mean body weight (kg) of lactating and nonlactating female reindeer of the Davis herd and weather indices; May-June growing-degree-days (MJGDD), previous year July growing-degree-days (JGDD), and natural logarithm of previous winter severity (LNWSEV) of the years 1987 to 1997.

	Lactating					Nonlactating				
	Weight	MJDD	JGDD	LNWSEV		Weight	MJDD	JGDD	LNWSEV
Weight	1.00				Weight	1.00			
MJDD	0.47	1.00			MJDD	0.55	1.00		
JGDD	0.02	0.20	1.00		JGDD	0.03	0.20	1.00	
LNWSEV	-0.14	-0.14	-0.30	1.00	LNWSEV	0.12	0.04	-0.30	1.00

Table 5.3 Mean weight ($\bar{x}$(kg)), daily rate of gain (kg d^{-1}) of Davis female reindeer calves, Nome growing-degree-days (GDD) and rate of heat accumulation (GDD d^{-1}) during June. Julian date (JDate) of handlings when calves were weighed.

1991					1992					1993					1994				
N	$\bar{x}$(kg)	S.E.	JDate	GDD	N	$\bar{x}$(kg)	S.E.	JDate	GDD	N	$\bar{x}$(kg)	S.E	JDate	GDD	N	$\bar{x}$(kg)	S.E	JDate	GDD
5	17.6	0.83	157	52.8	18	23.61	0.53	158	55.6	51	20.02	0.40	161	123.3	54	21.12	0.43	160	73.8
105	19.59	0.28	159	79.5	12	23.08	0.79	160	61.7	45	20.58	0.45	162	130.0	67	21.04	0.37	161	87.2
36	21.1	0.36	161	101.1	10	23.15	0.79	162	70.6	83	22.10	0.37	164	140.5	11	29.23	1.80	165	137.2
40	23.91	0.74	169	150.0	41	27.32	0.58	171	153.9	136	26.42	0.34	177	285.0	27	26.33	0.74	170	178.3
39	26.44	0.47	173	210.6	44	27.93	0.52	174	186.2	16	26.41	0.85	178	296.1	5	26.10	1.51	171	183.8
31	25.71	0.77	174	221.1	166	26.13	0.36	176	205.0	10	27.60	0.89	179	306.6	17	26.00	0.84	172	191.6
77	27.58	0.32	176	248.9	77	27.74	0.43	177	216.7						79	26.92	0.40	174	208.8
173	27.68	0.29	178	283.9											134	27.15	0.34	176	228.8
155	27.63	0.24	179	297.2											116	27.71	0.33	178	242.2
kg d^{-1}	0.44		GDD d^{-1}	10.4	kg d^{-1}	0.25		GDD d^{-1}	8.1	kg d^{-1}	0.35		GDD d^{-1}	9.6	kg d^{-1}	0.31		GDD d^{-1}	8.9

1995					1996					1997				
N	$\bar{x}$(kg)	S.E.	JDate	GDD	N	$\bar{x}$(kg)	*S.E.*	JDate	GDD	N	$\bar{x}$(kg)	S.E.	JDate	GDD
45	19.34	0.42	158	46.1	8	21.44	0.56	160	33.8	91	18.36	0.23	155	23.4
61	21.66	0.46	160	54.4	16	23.44	0.64	162	39.4	46	19.84	0.37	158	64.5
238	21.04	0.29	161	60.0	256	27.19	0.21	179	187.7	5	19.20	1.31	159	75.6
191	23.85	0.28	163	68.3	127	28.92	0.31	181	201.1	109	21.92	0.27	163	107.8
81	18.59	0.39	164	72.2	257	30.16	0.22	186	251.1	29	21.05	0.47	165	125.0
					114	31.37	0.29	189	290.0	49	23.86	0.44	169	158.9
					110	30.22	0.32	190	309.4	100	26.68	0.34	175	207.8
										158	26.16	0.25	177	232.3
										183	27.44	0.23	178	238.9
										69	28.76	0.44	181	272.8
										170	28.85	0.25	184	301.2
kg d^{-1}	0.13		GDD d^{-1}	2.9	kg d^{-1}	0.3		GDD d^{-1}	8.9	kg d^{-1}	0.39		GDD d^{-1}	9.3

Appendix A

Example of an Ecological Site Description (ESD) of the Seward Peninsula

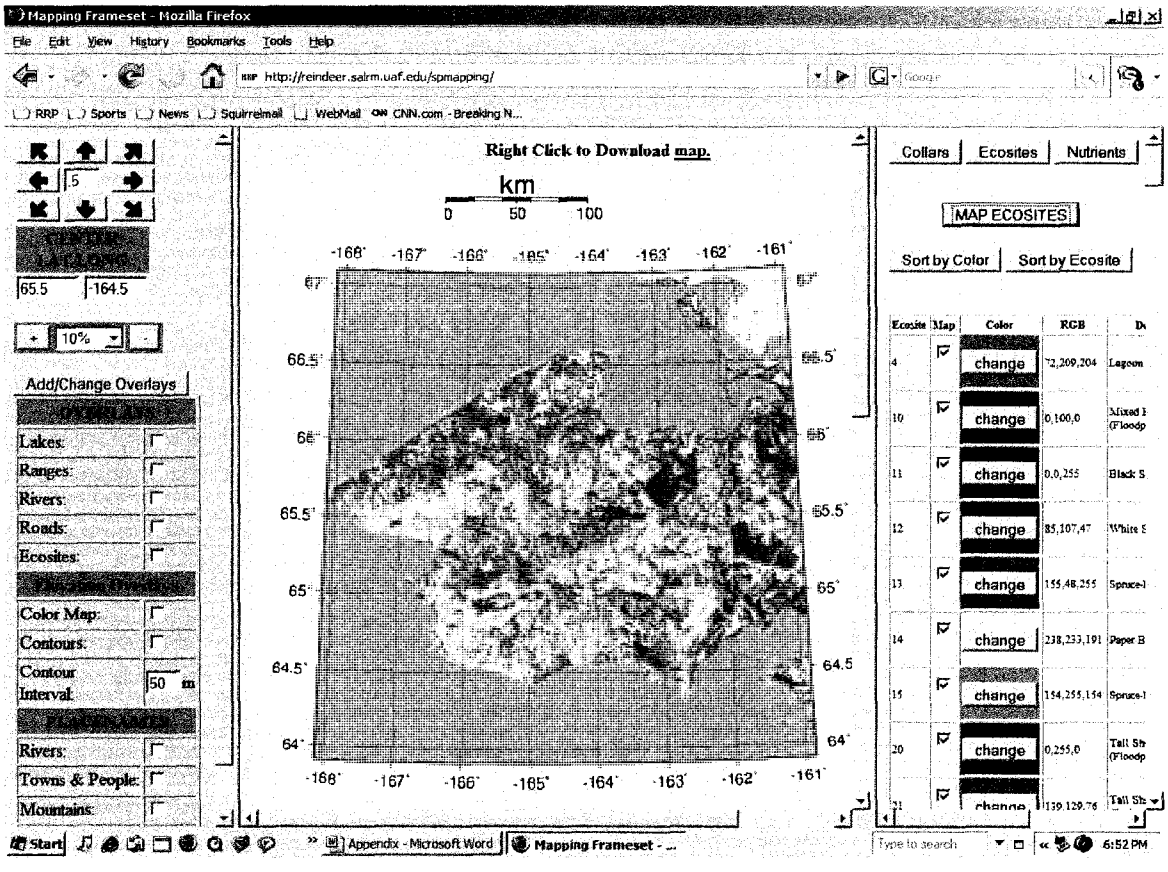
ECOLOGICAL SITE NO. 42A NAME: LOW SHRUB-WATER SEDGE (TUSSOCK TUNDRA)

A. Physical Characteristics
FEATURES. -- This site occurs in combination with other wet sites on broad depressions and coastal plains.
VEGETATION -- Bigelow sedge *(Carex bigelowii),* water sedge *(C. aquatilis),* northern labrador tea *Ledum decumbens),* and dwarf arctic birch *(Betula nana)* are the dominant vegetation on this site.
Lichens and succulent forbs can also be found hidden throughout the understory.
VEGETATION PRODUCTION (Air Dry). -- Grasses and grasslikes comprise 43 percent forbs 3 percent and shrubs 54 percent of the vegetative production. Annual vascular plant production yields 790 lb/ac and live lichen biomass yields 150 lb/ac.
VALUE FOR GRAZING REINDEER. -- This site is best suited for summer and fall range. Water sedge, grasses, and new deciduous growth provide high levels of digestible protein. Some lichen occurs on this site, but this site is not recommended for use as winter range. The lichens, however, can be important supplemental reindeer forage in the fall.

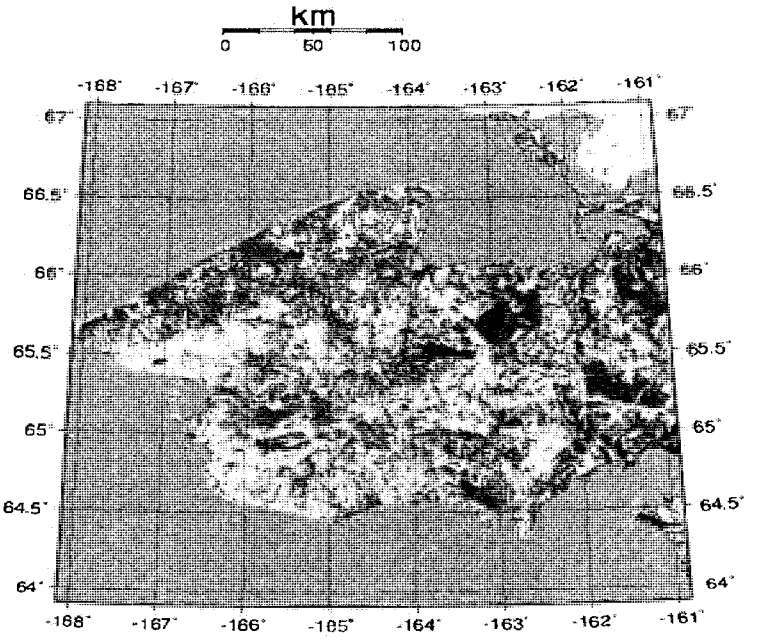
Appendix B

Interactive mapping of nutrients in reindeer forage across the Seward Peninsula landscape

B.1 Screen of mapping program demonstrating menu of interactive mapping program. Note the pan and zoom features and menu for input of locations of satellite collared reindeer (collars), ecosites and nutrients.

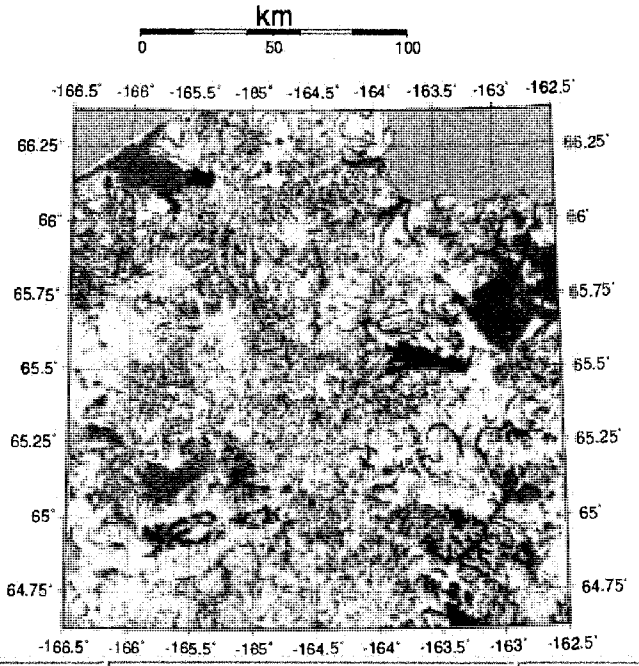


B.2 Map and legend of ecological sites of the Seward Peninsula generated by the proprietary software developed for management of reindeer on the Seward Peninsula, Alaska.



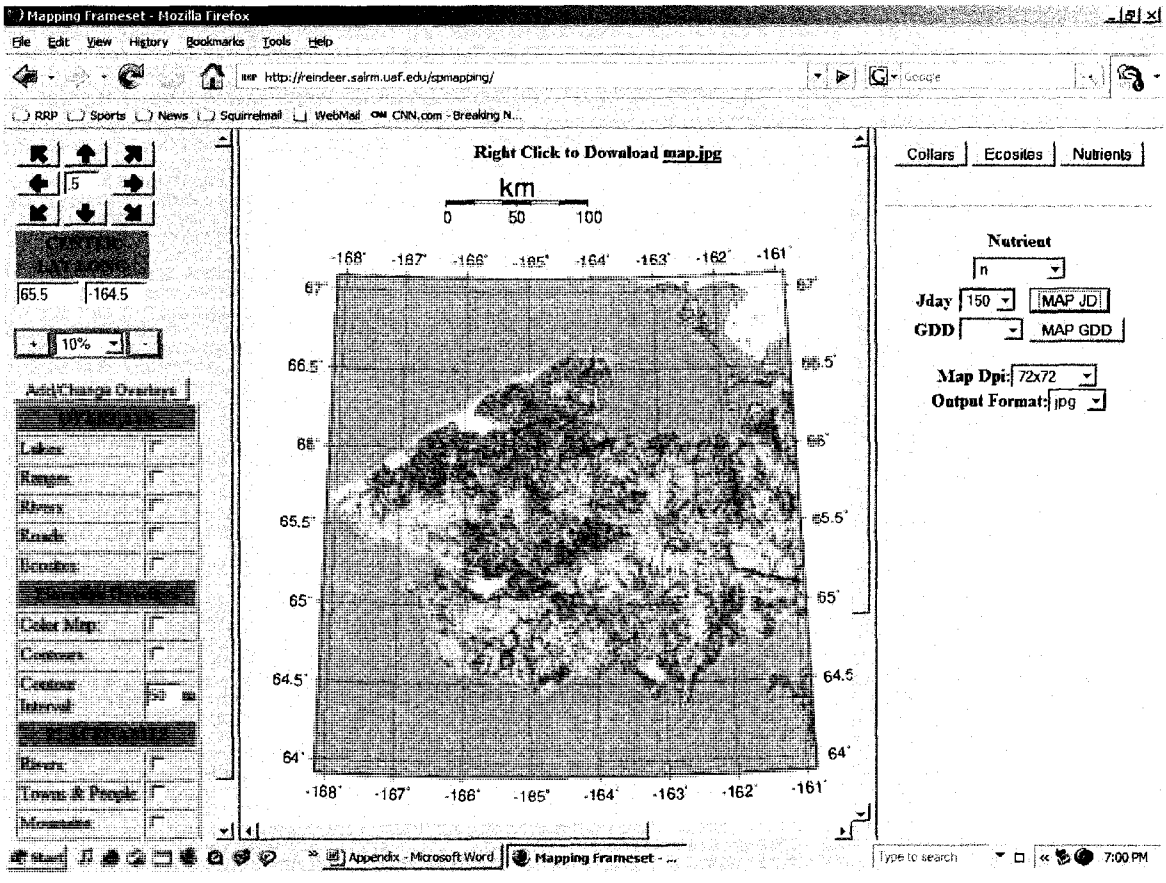
4	Lagoon	50	Dunes (Beach)
10	Mixed Forest (Floodplain)	51	Marsh (Tidal)
11	Black Spruce	52	Sedge (Wet Meadow)
12	White Spruce (Upland)	54	Sedge (Drainageway)
13	Spruce-Lichen (Upland)	55	Cottongrass-Water Sedge (Low Center Polygons)
14	Paper Birch (Upland)	56	Grass or Sedge (Breached Lake Bed)
15	Spruce-Lichen (Palsa)	57	Sedge (Wet Lake Bed)
20	Tall Shrub (Floodplain)	60	Lichen (Tussock Tundra)
21	Tall Shrub (Drainageway)	61	Lichen-Meadow (Mountain)
22	Tall Shrub (Hillside)	63	Lichen-Sedge (Coastal Tundra)
32	Mixed Shrub (Tundra)	64	Lichen Sedge Meadow
34	Low Shrub (Floodplain)	65	Lichen Slope (Upland)
35	Shrub-Birch or Shrub-Willow (Hillside)	66	Lichen Mat (Lowland)
41	Shrub Meadow (Mountain)	70	Lichen Granitic Slope (Alpine)
42	Low-Shrub-Water Sedge or Low Shrub-Cottongrass (Tussock Tundra)		
43	Low Shrub-Sedge or Low Shrub-Lichen Meadow (Alpine)		

B.3 Zoomed in from previous map of ecological sites on the Seward Peninsula.

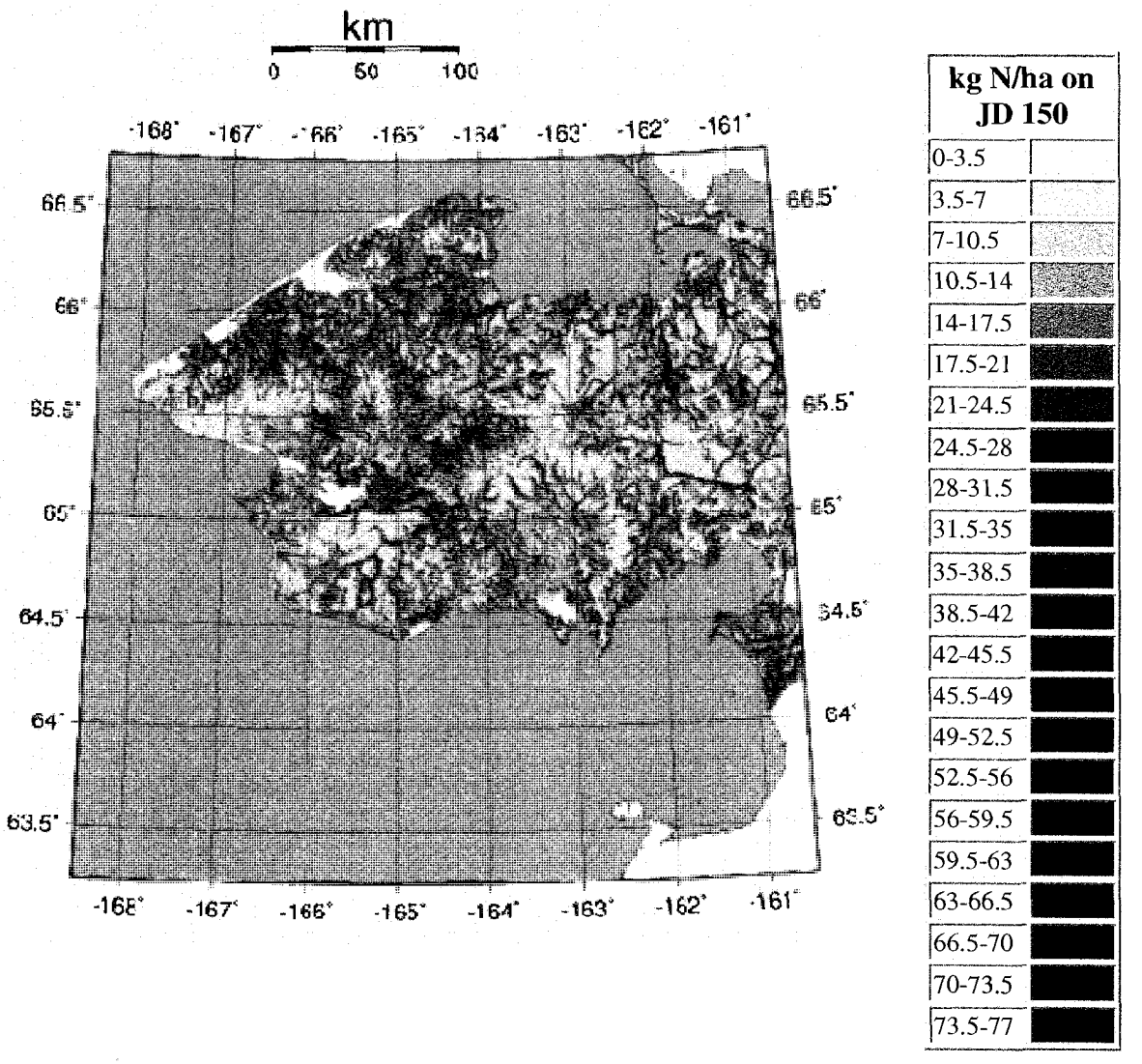


4	Lagoon	45	Water Sedge-Muskeg (Bog-Fen)	74	Dryas Lichen (Ridges)
10	Mixed Forest (Floodplain)	50	Dunes (Beach)	80	Lava Bed
11	Black Spruce	51	Marsh (Tidal)	81	Barren
12	White Spruce (Upland)	52	Sedge (Wet Meadow)	82	Riverwash
13	Spruce-Lichen (Upland)	54	Sedge (Drainageway)	90	Burned Forest
14	Paper Birch (Upland)	55	Cottongrass-Water Sedge (Low Center Polygons)	91	Burned Tundra
15	Spruce-Lichen (Palsa)	56	Grass or Sedge (Breached Lake Bed)	44-22	Shrub-Lichen (Upland) - Tall Shrub (Hillside) Complex
20	Tall Shrub (Floodplain)	57	Sedge (Wet Lake Bed)	60-20	Lichen (Tussock Tundra) - Tall Shrub (Floodplain) Complex
21	Tall Shrub (Drainageway)	60	Lichen (Tussock Tundra)	60-32	Lichen (Tussock Tundra) - Mixed Shrub (Tundra) Complex
22	Tall Shrub (Hillside)	61	Lichen-Meadow (Mountain)	60-80	Lichen (Tussock Tundra) - Lava Bed Complex
32	Mixed Shrub (Tundra)	63	Lichen-Sedge (Coastal Tundra)	61-43	Lichen Meadow (Mountain) - Low Shrub-Sedge or Low Shrub-Lichen Meadow (Alpine) Complex
34	Low Shrub (Floodplain)	64	Lichen Sedge Meadow	63-52	Lichen-Sedge (Coastal Tundra) - Sedge (Wet Meadow) Complex
35	Shrub-Birch or Shrub-Willow (Hillside)	65	Lichen Slope (Upland)	64-43	Lichen Sedge Meadow - Low Shrub-Sedge or Low Shrub-Lichen Meadow (Alpine) Complex
41	Shrub Meadow (Mountain)	66	Lichen Mat (Lowland)	70-41	Lichen Granitic Slope (Alpine) - Lichen Meadow (Mountain) Complex
42	Low-Shrub-Water Sedge or Low Shrub-Cottongrass (Tussock Tundra)	70	Lichen Granitic Slope (Alpine)		
43	Low Shrub-Sedge or Low Shrub-Lichen Meadow (Alpine)	71	Dryas Limestone Slope		
		72	Bald Limestone Slope		

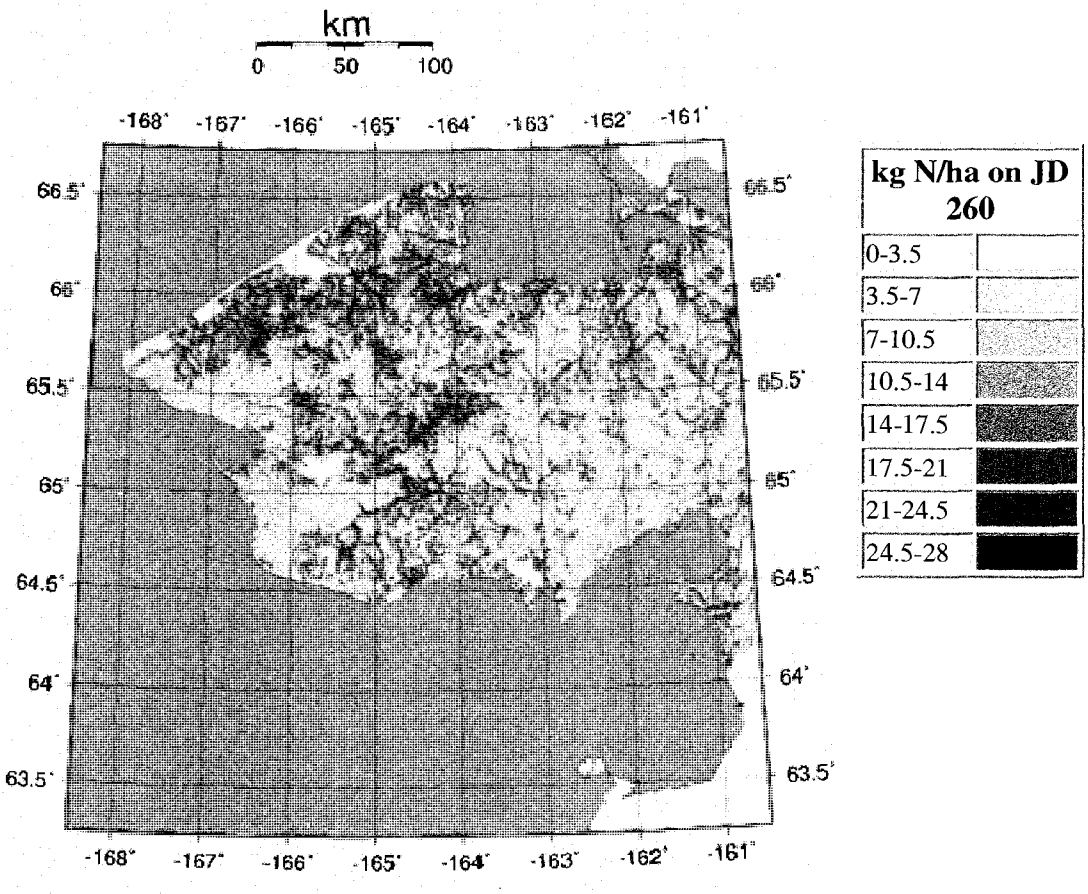
B.4 Screen of mapping program demonstrating menu of interactive mapping program. Note menu for input of nutrient of concern and day of the year.



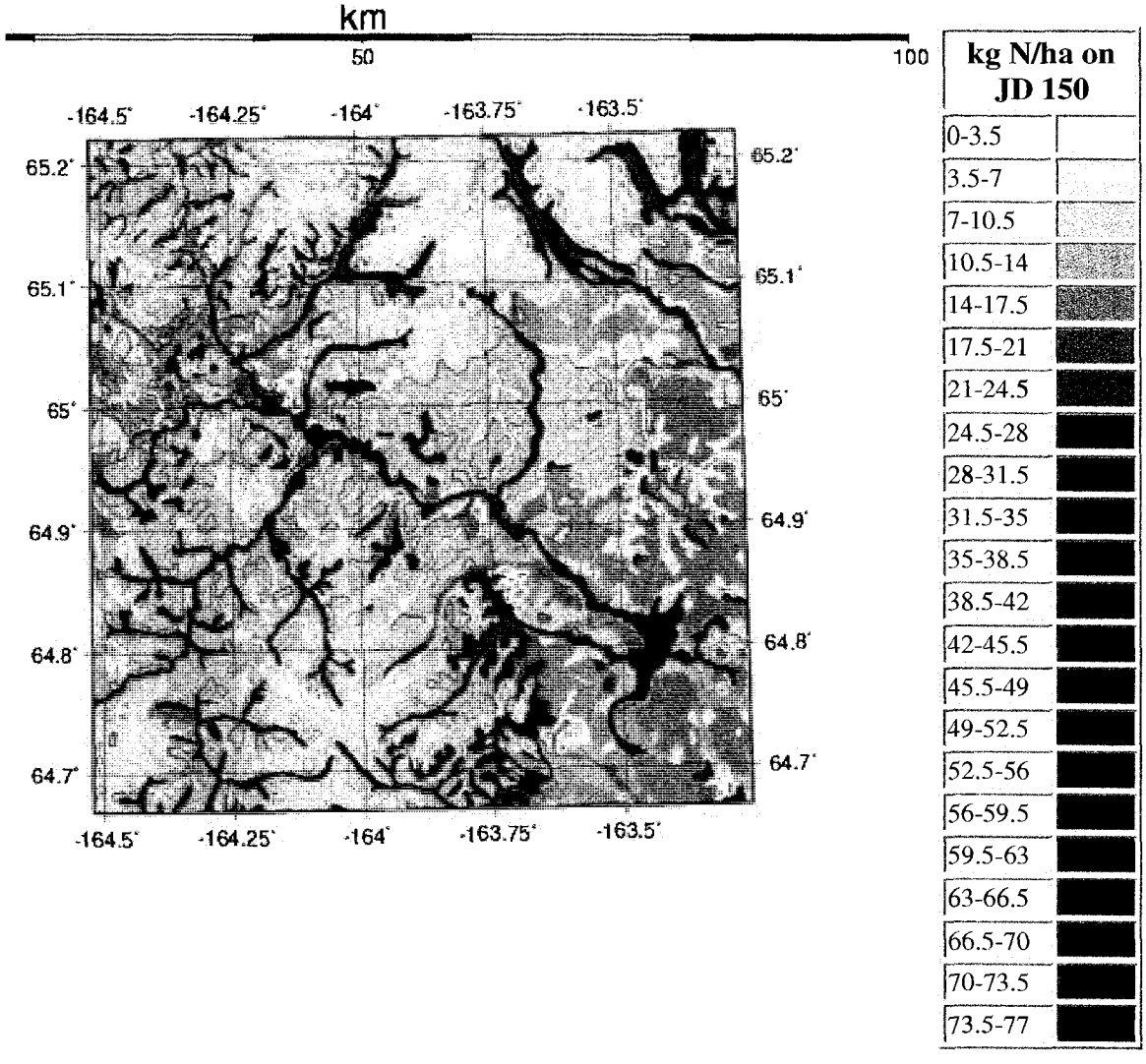
B.5 Map of cumulative nitrogen (kg N ha^{-1}) of reindeer forage plants per ecological site on Julian Date (JD) 150, Seward Peninsula, Alaska. Different ecological sites may have same N output and be categorized and mapped equivalently (same color).



B.6 Map of cumulative nitrogen pool (kg N ha^{-1}) of reindeer forage plants per ecological site on Julian Date (JD) 260, Seward Peninsula, Alaska. Different ecological sites may have same N output and be categorized and mapped equivalently (same color).



B.7 Map of cumulative nitrogen pool (kg N ha^{-1}) of forage plants on the Seward Peninsula Alaska has been zoomed in from previous map (B.6) demonstrating interactive mapping program with features to meet the resolution requirements of producers and land managers



Appendix C

The role of minerals in ruminant nutrition

Although the normal serum mineral concentrations for reindeer have not been established, normal or baseline serum levels for cattle have been estimated and are reported from NRC, (1996).

Serum Ca levels are usually not responsive to Ca intake but are maintained homeostatically between 9 and 11 mg/dL because reserves in bone are mobilized to maintain levels in blood. Serum P concentrations below 4.5 mg/dL indicate a deficiency (McDowell, 1992). Signs of Mg deficiency can be found when serum levels fall below 15 μg/mL but symptoms of grass tetany appear when serum values fall below 12 μg/mL. Serum Na concentration is generally not a good measure of status but serum values of 135-145 mEq/L are found with few observed deficiency or toxic disorders. Serum Cu levels of 0.7 to 0.1.0 μg/mL and serum Zn levels of 0.8 – 1.2 μg/mL in ruminants are considered normal. Iron is present in serum in a non-hemoglobin form and normal values are 1.1 – 1.2 μg/mL and normal blood values for Se range between 0.2-0.24 μg/mL.

Calcium is the most abundant mineral in the body; 98% found in the skeleton and teeth with the remaining 2% is found in soft tissue and extracellular fluids. Calcium is required for proper clotting of blood, membrane permeability, muscle contraction, nerve conductivity, muscle contraction, secretion of hormones and activation of certain enzymes. Blood Ca levels will drop only when stores in bone have been depleted where bones will become fragile because they have been so demineralized. Calcium deficiency is signaled by osteomalacia as a result of bone demineralization which results in weak,

soft bones, swollen tender joints, enlarged bone ends, arched back, stiffness of the legs and development of beads on the ribs (NRC, 1996). None of these symptoms have been reported for reindeer on the Seward Peninsula (Reindeer Herders Association members, pers comm.).

Inadequate phosphorus is the most prevalent mineral deficiency among the world's livestock. Approximately 80 % of the phosphorus found in the body is contained in the skeleton and teeth. Phosphorus is required for synthesis of DNA and RNA, energy transfer in the body as part of the ATP molecule, phospholipid formation and maintenance of acid-base and osmotic balance. Phosphorus is also required by rumen microorganisms for their growth and cellular metabolism. Phosphorus deficiency signs are reduced feed intake, feed efficiency and growth, low reproduction, reduced milk output and fragile bones.

Most of the Mg contained in the body occurs in bones although it also occurs substantially in intra and extracellular fluids. Magnesium is needed as a component and catalyst of enzymes involved in the metabolism of carbohydrates, lipids, nucleic acids and proteins. Magnesium is essential for oxidative phosphorylation leading to ATP formation, modulates neuromuscular activity and helps maintain the integrity of cell membranes by binding to phospholipids and as a major component of the skeleton. Rumen microorganisms require magnesium to catalyze many of the enzymes essential for cellulytic activity. Serum levels are influenced by both magnesium in the diet and mobilization from bone, although slowly. When animals are first given a low-magnesium diet they show a rapid decline in serum levels but gradually recover due to

mobilization of skeletal magnesium. Hypomagnaesaemia is most likely to develop following the onset of lactation. Subnormal serum calcium values usually accompany the low serum magnesium while shifts in hypomagnaesaemia and hypocalaemia are often correlated.

Sodium is the major cation in extracellular fluid and in association with chloride maintains osmotic pressure, regulates acid–base equilibrium and controls water metabolism in the body. Sodium also functions in muscle contraction, nerve impulse conduction and transport of glucose and amino acids across membranes. Sodium is the mineral most likely to be deficient when ruminants receive no mineral supplementation because most plants do not require or contain much sodium. Sodium deficiency signs include picea and reduced feed intake, growth and milk production.

Trace minerals are needed by ruminants for structural, physiological, catalytic and regulatory functions. Trace minerals provide structural components of organs and tissues like the contribution of zinc to bone and membrane development. Trace minerals in body fluids and tissues act as electrolytes to maintain osmotic pressure, acid-base balance and membrane permeability. Trace elements serve as components to many metalloenzymes that are required for a number of metabolic activities such as energy production, protein digestion, cell replication, antioxidant activity and wound healing.

Zinc and Cu were reported as the trace minerals likely to be deficient in livestock production Reproductive performance of ruminants may be compromised if copper or zinc status is marginal or deficient. Copper deficiency causes delayed or suppressed estrus, decreased conception, infertility and embryo death in cattle. Zinc deficiency has

been associated with decreased fertility, abnormal estrus, abortion and altered myometrial contractibility with prolonged labor.

Zinc functions as an important component or catalyst for over 200 enzymes that are in involved in carbohydrate and protein metabolism in the ruminant (Church, 1988). Signs of Zn deficiency include reduced feed intake, feed efficiency and weight gain, listlessness, excessive salivation, reduced testicular growth, swollen feet, lesions or hair discoloration around the neck head and nostrils. The role of Zn in reproduction appears to be manifested more in males than females. Zinc appears to be associated as an activator of enzymes involved in steroidgenesis of testosterone and related hormones. In the female, deficiencies cause impaired fertility and abnormal estrous behavior. Zinc is also important for the development and functioning of the immune system.

Iron is an essential compound of a number of proteins involved in oxygen transport or utilization. The major portion of body Fe is in hemoglobin (60-70%), myoglobin, (3%) and in storage (26%), a small percentage in enzymes (<1%). The iron requirement is approximately 50 mg/kg diet in beef cattle. A deficiency in iron causes anemia, listlessness, reduced food intake and weight gain, pale mucus membranes and atrophy of the papillae of the tongue.

Appendix D

Calibration of liver Cu concentrations in reindeer reported as weight weight (WW) or dry matter (DM) basis

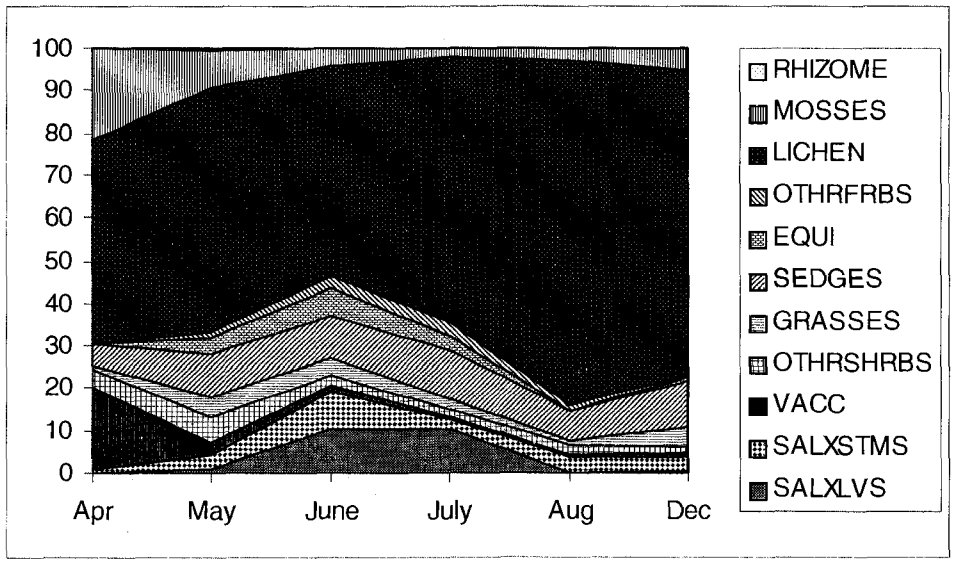
Results of mineral analysis of tissues are reported in the literature on a wet weight (WW) or dry matter basis which is often confusing and sometime makes it difficult to compare results of other studies. We determined the percent moisture of dried liver samples sent to the Soil and Plant Analytical Laboratory in Palmer, Alaska that could be used as a correction factor to convert results as WW. We also compared these results to results obtained from another analytical laboratory which reported results on a WW basis. Liver tissue samples were collected from slaughtered steers and adult females during the winter months, January or February 1997. Approximately 50 grams of liver from the caudate lobe of the liver were collected by personnel wearing sterile latex gloves and all stainless steel collection and dissection tools were cleaned with ethanol between collections of samples. All samples were placed in whirlpak™ bags, immediately frozen, and transported to the University of Alaska Fairbanks. Twenty samples of liver were randomly selected and partitioned into subsamples. One set of subsamples was kept frozen and sent to the Analytical Sciences Laboratory, Holm Research Center, University of Idaho and analyzed for concentrations of Cu reported μg/g wet weight (WW). Another respective subsample of liver was weighed and placed in sterile weighing boats and dried at 100^{O}C for 72 hrs to determine percent moisture. All other liver samples were dried at 100^{O}C for 72 hrs ground using a Wiley mill with a resin 20mm mesh, placed in whirlpak™ bags and sent to the Soil and Plant Analytical Laboratory in Palmer, Alaska

where they were analyzed for concentration of Cu reported as μg/g dry matter (DM) basis. Regression analysis was used to determine moisture correction factors and correlation coefficients for Cu concentrations reported as WW and DM concentrations from the two analytical labs. Liver samples lost approximately 70 % moisture and percent dry matter of liver was determined to be 29.5 ± 0.4, N = 21. Liver concentrations of dried samples analyzed at the Soil and Plant Analytical Laboratory in Palmer, Alaska were regressed against the results obtained from replicate samples sent to the Analytical Sciences Laboratory, Holm Research Center, University of Idaho; *Cu* μg/g dry weight = -3.8 +3.2(Cu μg/g wet weight). N = 22, R^2 = 0.97, $p < 0.01$. The regression coefficient (3.2) is in agreement with the % dry matter estimation (30%) and the R^2 value indicates results from the two analytical laboratories are highly correlated.

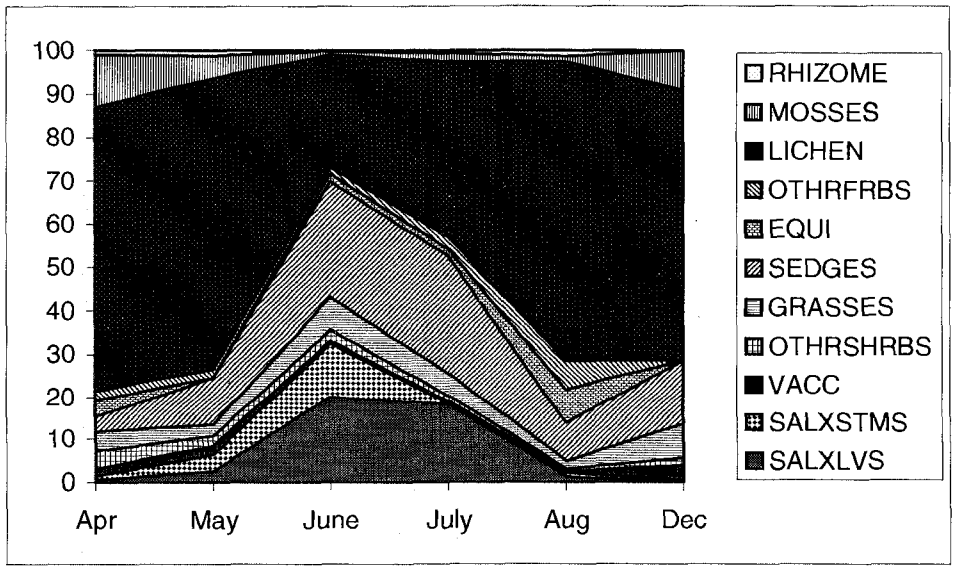
Appendix E

Percentage of plant growth form in seasonal diets of reindeer across range allotments of the Seward Peninsula, Alaska

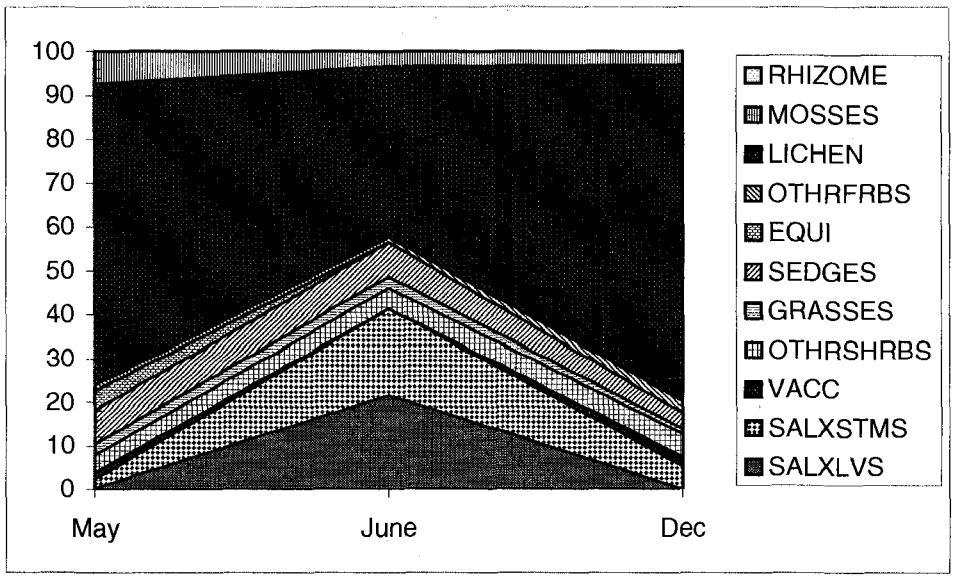
Davis range



Gray range



Noyakuk range



Olanna range